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DEPARTMENT OF REGISTRATION AND EDUCATION



Ironton and Galesville (Cambrian) Sandstones in Illinois and Adjacent Areas

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ILLINOIS STATE GEOLOGICAL SURVEY

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IRONTON AND GALESVILLE (CAMBRIAN) SANDSTONES IN ILLINOIS AND ADJACENT AREAS

Grover H. Emrich

ABSTRACT

Cambrian sediments in the Upper Mississippi Valley were deposited on a broad stable shelf, forming a sequence of uniform, widespread, largely clastic units. Within this sequence, the Ironton and the underlying Galesville Sandstones form an important source of ground water throughout northern Illinois and southeastern Wisconsin. The sandstones crop out on the flanks of the Wisconsin Arch and generally dip southward, reaching a depth of about 5000 feet in central Illinois. The Ironton Sandstone is fine to coarse grained, silty, poorly sorted, and carries the Elvinia fauna in the upper 10 feet. The underlying Galesville Sandstone is fine to medium grained, partly coarse grained, nonsilty, well sorted, and, in the lower part, fossiliferous in places.

The sandstones thicken southward to a maximum of 250 feet southwest of Chicago, Illinois, and then thin rapidly. Dolomite is rare in southern Wisconsin and extreme northern Illinois but increases southward from the area of maximum thickness. Dolomite is consistently more abundant in the Ironton Sandstone. High oolite concentrations occur along the eastern and western borders of Illinois.

The Ironton and Galesville Sandstones are mature, well sorted orthoquartzites. Their heavy mineral assemblages are composed chiefly of well rounded tourmaline, zircon, ilmenite, leucoxene, and varying amounts of etched garnet. Grain analyses of the sand fractions indicate little variation in median diameter or sorting. The maximum diameters of the grains are generally smaller to the south.

Cross-bedding, primarily of the trough type, is common. In the Galesville Sandstone, orientation is to the southwest, with much local variation; in the Ironton Sandstone, orientation is to the east in western Wisconsin but to the southwest in the rest of the outcrop area.

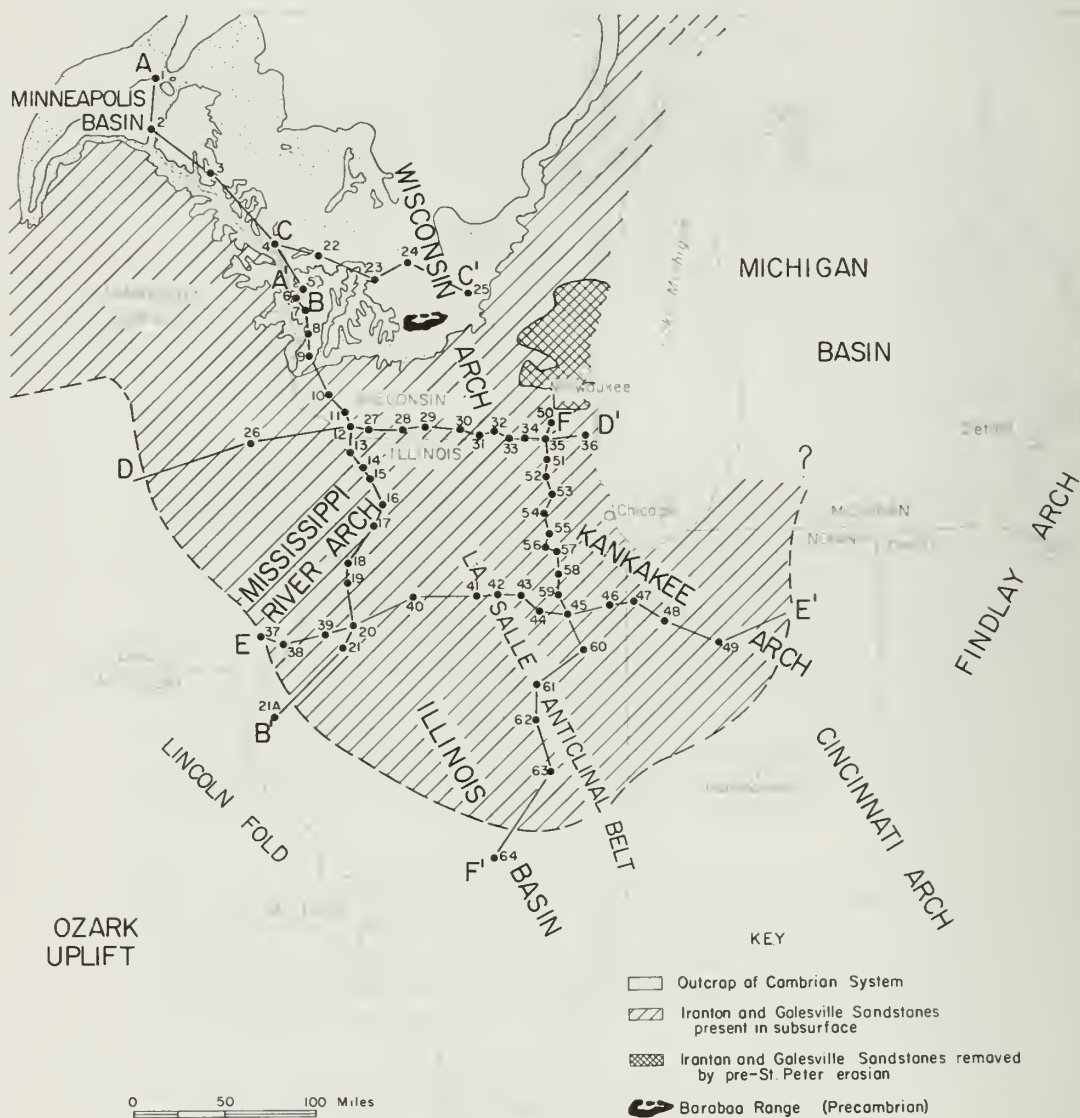


Figure 1 - Index map of the Upper Mississippi Valley showing tectonic setting, areal distribution of the Ironton and Galesville Sandstones, and lines of cross sections.

The sandstones were derived from preexisting sedimentary rocks, primarily in the northern Michigan Highlands, with possible secondary sources from the Transcontinental Arch and the Canadian Shield. These sediments were deposited on a broad, shallow shelf with clastic deposition to the north and carbonate deposition to the south. Bank conditions existed along the eastern and western margins of Illinois.

Together, the Ironton and Galesville Sandstones form the most consistently permeable and productive aquifer in northern Illinois and southern Wisconsin. The transmissivity of the aquifer decreases from north to south, as carbonate content increases. The Galesville Sandstone is more permeable than the Ironton Sandstone. Despite many years of heavy pumping from the aquifer, potable water under high artesian head is widely available from these sandstones.

INTRODUCTION

The Ironton and Galesville Sandstones of Cambrian age are an important source of municipal and industrial water supplies in much of northern Illinois (Suter et al., 1959). These sandstones crop out extensively in Wisconsin and Minnesota and are traced in the subsurface into Illinois where their nearest approach to the surface is at a depth of about 100 feet near Oregon. They were deposited under stable crustal conditions over a wide area in the Upper Mississippi Valley and form a regional aquifer characterized by the continuity of many units and only gradual facies changes.

The Ironton Sandstone directly overlies the Galesville Sandstone, but differences in lithologic characteristics cause them to be classified as separate formations. Although some water-bearing characteristics can be related to the lithologic differences, both sandstones are sources of ground water, and they form a single hydrogeologic unit. In reports on ground-water resources they are frequently treated as a single unit, for convenience, called the Ironton-Galesville Sandstone. In local areas, where the Ironton and Galesville Sandstones are difficult to separate, and in most drillers' logs, the term Ironton-Galesville Sandstone is useful.

This investigation was undertaken to determine the stratigraphic relations, texture, mineralogy, and geologic history of the Ironton and Galesville Sandstones to provide a basis for study of their aquifer characteristics.

Detailed hydrologic information on the Ironton and Galesville Sandstones is limited. Reports on the Milwaukee-Waukesha, Wisconsin, area (Foley et al., 1953) and the Chicago, Illinois, area (Suter et al., 1959) give brief discussions of the Ironton and Galesville Sandstones. Walton and Csallany (1962) give additional data.

Location

The area covered by this study is within the Upper Mississippi Valley (fig. 1) chiefly in Illinois, but the outcrop area in Wisconsin is discussed and references are made to areas in Iowa, Indiana, and Minnesota. The Ironton and Galesville Sandstones crop out in an arcuate band, 10 to 30 miles wide, that extends from the

CAMBRIAN SYSTEM															
Winchell (1886)	Shole	St. Croix Formation		Dresbach Sandstone	Dresbach	Berkey (1897)	Wolcott (1914)	Thwaites (1923)	Trowbridge and Atwater (1934) Twenhofel, Raasch, and Thwaites (1935)	Howell et al. (1944)	Buschbach (1964) and This Report				
		St. Croix Formation													
	Hinckley Sondrock	Shale	Dresbach	Mt. Simon	Eou Claire Formation	Galesville Member	Ironton Member	Franconio Sandstone				Dresbach Formation	Galesville Member	CROIXAN SERIES	DRESBACHIAN STAGE
Shale	Dresbach Sandstone	Dresbach	Mt. Simon	Eou Claire Formation	Galesville Member	Ironton Member	Franconio Sandstone	Dresbach Formation	Galesville Member	CROIXAN SERIES	DRESBACHIAN STAGE				
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Figure 2 - Development of the stratigraphic nomenclature of the Dresbachian and Franconian Stages of the Cambrian System in the Upper Mississippi Valley and present usage in Illinois.

upper peninsula of Michigan to south-central Wisconsin and thence up the Mississippi River into Minnesota. In much of eastern Wisconsin the bedrock is poorly exposed, as it is buried under glacial sediments. The Ironton and Galesville Sandstones are well exposed in central Wisconsin, and they occur in large continuous bluffs along the Mississippi River in western Wisconsin and southeastern Minnesota.

Methods

Petrographic analyses of heavy minerals and light minerals, X-ray analyses of clay minerals, and sieve analyses of sandstones were made on outcrop and well samples. Cross-bedding and other directional properties were measured in many outcrops.

Visual estimates of carbonate and oolite distribution, maximum grain size, and median diameter were made on cuttings from 179 wells. In addition, thickness and structure maps were made from well records available in 1961 in Illinois, Wisconsin, Iowa, and Indiana.

The grain-size descriptions of the Ironton and Galesville Sandstones in the outcrop region are based on sieve analyses of samples. In well cuttings and cores, grain-size descriptions are based on visual estimations (Emrich and Wobber, 1963) and on sieve analyses of samples from selected wells. Grain-size nomenclature follows the Wentworth scale.

Acknowledgments

The State Geological Surveys of Wisconsin, Iowa, and Indiana and the U. S. Geological Survey, Ground-Water Branch offices at Madison, Wisconsin, and Indianapolis, Indiana, kindly supplied basic data from wells.

M. E. Ostrom, of the Wisconsin Geological Survey, made several field visits with the author and offered many constructive suggestions. Paul E. Potter, of the Illinois State Geological Survey, now at Indiana University, and W. C. Krumbein and L. L. Sloss of Northwestern University gave helpful suggestions.

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The writer especially appreciates the help of Frank Wobber, who assisted in the collection and preparation of material for this report. John Rodgers served as field and laboratory assistant during the summer of 1959.

This report is adapted from a dissertation submitted to the University of Illinois as partial fulfillment of requirements for a doctor of philosophy degree. It is based on research at the Illinois State Geological Survey, under the direction of Dr. G. B. Maxey.

STRATIGRAPHY

The Ironton and Galesville Sandstones are both of Croixan (Upper Cambrian) age, but the Ironton is assigned to the Franconian Stage and the Galesville to the underlying Dresbachian Stage (fig. 2).

The presence of rocks of Cambrian age in the Upper Mississippi Valley was recognized more than 100 years ago, but only brief lithologic descriptions are given in early reports (Owen, 1852; Shumard, 1862; Hall, 1863; and Whitfield, 1878). In 1873, Winchell correlated the basal sandstones with the Potsdam Sandstone of New York and called the overlying strata the St. Croix Sandstone. In a description of the Cambrian stratigraphy in Minnesota, Winchell (1886) introduced the name Dresbach Sandstone for a sandstone overlain and underlain by shales. The Dresbach Sandstone was essentially the present Ironton and Galesville Sandstones, the shale above was the Franconia, and the shale below was the Eau Claire. The Dresbach Sandstones and the overlying shale (including sandstone) were grouped by Winchell as the St. Croix Formation.

Berkey (1897) gave the name Franconia to the shale and sandstone overlying the Dresbach Sandstone. In 1923, Thwaites differentiated the basal sandy beds of the Franconia as the Ironton Member. Thwaites (1927) recognized many of the formations of the outcrop area in samples from wells in northern Illinois.

The name Galesville was introduced by Trowbridge and Atwater (1934) to replace the name Dresbach, which they expanded to include all the Cambrian strata below the Franconia. Workman (1935) accepted the name Galesville as a replacement for Dresbach in Illinois. In the outcrop region in southern Wisconsin, Twenhofel, Raasch, and Thwaites (1935) defined the basis for differentiation of the Ironton and Galesville as the change from coarse- and medium-grained, poorly sorted sandstone above to finer grained, well sorted sand below. In Illinois, sands previously included in the top of the Galesville or the base of the Franconia were recognized as equivalent to the Ironton by Willman and Payne (1942). In much of northern Illinois, Workman and Bell (1949) assigned a medium- and coarse-grained, glauconitic, dolomitic sandstone at the base of the Franconia to the Ironton Member. The Ironton was first raised to formational rank in Illinois by Willman and Templeton (1952).

In the late 1940's, subsurface studies by J. S. Templeton in the Oregon Quadrangle in north-central Illinois, and later by Templeton and M. V. Strantz in a broader area (Illinois State Geological Survey, unpublished data), led to the restriction of the Galesville in Illinois to the lower 20 to 100 feet of primarily fine-grained, nondolomitic, and well sorted sandstone. Above the Galesville, they assigned to the Ironton Formation four widespread units consisting of a dolomitic sandstone at the top, underlain by fine to coarse, generally poorly sorted sandstone, a second dolomitic sandstone, and poorly sorted sandstone at the base. These units were recognized in northeastern Illinois and designated as members of the Ironton Sandstone in descending order, Mooseheart Member, Marywood Member, Fox Valley Member, and Buelter Member (Buschbach, 1964). In the present study, these units were differentiated in many wells throughout the region.

Galesville Sandstone

Definition

Trowbridge and Atwater (1934, p. 45) proposed the name Galesville Member for the lower part of beds originally called Dresbach by Winchell. In the type section, a bluff along Beaver Creek near Galesville, Wisconsin, they assigned 86 feet of fine- to coarse-grained sandstone to the Galesville. They described the Galesville of the type section as underlying the fossiliferous, iron-stained sand-

stone of the Ironton Member of the Franconia Formation and overlying fossiliferous sandstones of the Eau Claire Member. They described the Galesville as "Coarse, poorly sorted sandstone with white and blue calcareous clay. Unfossiliferous except for worm borings." The underlying 36 feet of sandstone of the Eau Claire Member was described as "Coarse, poorly sorted sand. Lithologically similar to Galesville but containing scattered brachiopod shells."

During the present study, the following description of the type section was made at the northeast end of the bluff on the east bank of Beaver Creek, at Galesville, Wisconsin, 100 yards south of Wisconsin Highway 53 (NE NE NW 33, 19N-8W, Trempealeau County, Wisconsin):

Ironton Sandstone (39 feet)

Bed	Feet
24. Sandstone, glauconitic, brown, fine grained, thin bedded, fossiliferous	1.5
23. Sandstone, brown, fine to very fine grained, cross-bedded, fossiliferous	2.0
22. Sandstone, brown, medium to coarse grained, little fine grained, cross-bedded, fossiliferous	3.0
21. Sandstone, brown, fine to medium grained, trace coarse grained, massive bedded, partly cross-bedded, with inter-bedded sandstone, silty, brown, fine to very fine grained, flaggy	4.5
20. "Wormstone"—Sandstone, silty to slightly silty, light brown, medium to coarse grained, trace fine grained, friable, massive bedded, weathers irregularly	4.5
19. Sandstone, white, coarse to medium grained, trace fine grained, massive bedded, cross-bedded	7.0
18. "Wormstone"—Sandstone, silty to very silty, yellowish brown, medium to coarse grained, trace fine to very fine grained, friable, massive bedded, weathers irregularly	2.5
17. Sandstone, slightly silty, white, coarse to medium grained, trace fine grained, massive bedded, little thin bedded, cross-bedded	14.0

Galesville Sandstone (88.4 feet)

16. Sandstone, white, fine to medium grained, little coarse and very fine grained, friable to compact, mostly massive bedded, partly cross-bedded	6.7
15. Sandstone, white, coarse to medium grained, little fine grained, medium bedded	0.7
14. Sandstone, white, fine to medium grained, little coarse grained, medium to massive bedded, cross-bedded	3.5
13. Sandstone, white, fine to very fine grained, trace medium grained, massive bedded, cross-bedded	12.0
12. Sandstone, white, medium to fine grained, little coarse grained, massive bedded with few thin beds, cross-bedded	6.3
11. Sandstone, silty, white, fine grained, little very fine grained, massive bedded, cross-bedded	3.0
10. Sandstone, white, medium to fine grained, little coarse and very fine grained, massive bedded, cross-bedded with few 6-inch beds of sandstone, white, medium to coarse grained	12.0
9. Covered	3.0
8. Sandstone, white, fine grained, friable, massive bedded	4.0
7. Sandstone, white to light yellow, fine to very fine grained, friable, medium bedded, cross-bedded, fossiliferous	2.0
6. Sandstone, trace silt, white, light brown, medium grained, little coarse and fine grained, friable, medium bedded, slightly fossiliferous	1.5

Galesville Sandstone, continued

Bed	Feet
5. Sandstone, white, fine to very fine grained, trace medium grained, friable, medium to massive bedded, cross-bedded, slightly fossiliferous	19.0
4. Sandstone, trace silt, white to light yellow, medium grained, little coarse to very coarse and fine grained, friable, massive bedded, cross-bedded, fossiliferous	2.0
3. Sandstone, white to yellow, medium grained, little coarse and fine grained, friable, massive bedded, cross-bedded, fossiliferous	12.7
Eau Claire Formation (12 feet)	
2. Siltstone, glauconitic, sandy, light yellowish buff, tough, thinly bedded with green shale partings	2.5
1. Sandstone, glauconitic, light buff, very fine grained, little fine grained, trace medium grained, massive bedded, cross-bedded, fossiliferous	9.5

Although Trowbridge and Atwater gave a thickness of 86 feet for the type Galesville, they assigned only 10 feet to the Ironton at the top and included all the fossiliferous sandstone at the base in the Eau Claire. It appears, therefore, that they called beds 8 to 20 Galesville, which is 79.2 feet thick. The present revision of the type section lowers the top of the Galesville about 28 feet and lowers the base about 37 feet. As revised, the Galesville at the type locality extends upward from the top of the siltstone or fine-grained sandstone (bed 2) of the Eau Claire Formation to the base of the silty sandstone (bed 17) of the Ironton Sandstone.

Lithology

In the outcrop area the Galesville consists of interbedded layers of sandstone that range from fine to coarse grained. In central Wisconsin at Woodhill, only fine-grained sandstone is present. The sand is generally well sorted and finer grained than the sand in the overlying Ironton Sandstone. It lacks silt and shale. Observations along the outcrop belt (fig. 3) indicate that the Galesville Sandstone is a widespread, easily recognizable unit.

The Galesville thins eastward from almost 90 feet thick at Galesville to 50 feet thick at Friendship Mound on the Wisconsin Arch in central Wisconsin (fig. 3, cross section C-C'). Depositional thinning northward also occurs along the Mississippi River as the Precambrian outcrop is approached (fig. 3, cross section A-A'). At Franconia and Taylors Falls, Minnesota, the Galesville Sandstone is absent and the overlying Ironton Sandstone rests on the Eau Claire Formation or Precambrian rocks.

In subsurface, the Galesville consists of generally fine-grained, well sorted, white- to light-buff, friable, clean sandstone that is similar in most respects to the sandstone in the outcrop area. Its thickness is variable, as shown on the cross sections (figs. 4, 5).

Fauna

Descriptions of the faunas of the Galesville Sandstone are given by Twenhofel, Raasch, and Thwaites (1935, p. 1694-1696), Raasch (1935, p. 306), Howell et al. (1944), and Bell, Berg, and Nelson (1956, p. 424). The lower part of

the Galesville Sandstone, as redefined, corresponds to the *Aphelaspis* Zone of Howell et al. (1944). In addition, there are species of *Linguella* and *Acrotreta*.

A few rounded fragments of conodonts were found in one sample from the Galesville Sandstone (Charles Collinson, personal communication). Rounding of these fragments indicates either deposition in a high-kinetic environment or re-working of preexisting sediments containing conodonts.

Stratigraphic Relations

The contact between the Galesville and Eau Claire Formations is well defined in the outcrop area and reflects a sharp change in sedimentation. In central Wisconsin, along the Wisconsin Arch, local erosion occurred, as at Friendship Mound (fig. 3), so that the Galesville rests on the middle or lower part of the Eau Claire Formation.

In subsurface, the following criteria were used to separate the Galesville Sandstone from the Eau Claire Formation:

	Galesville Sandstone	Eau Claire Formation
Grain size	Fine and medium grained with minor amounts of coarse grained	Interbedded, very fine-grained sandstone and siltstone in the north (Wisconsin) grading to siltstone and shales to the south (Illinois)
Dolomite	Present in northeastern and east-central Illinois at the base as a brown to dark brown bed with minor amounts of fine-grained sand; rare elsewhere	Interbedded with or grading to very fine-grained sandstone, siltstone, or shale; buff to gray colored
Glaucanite	Minor amounts, very fine grained	Common, fine to medium grained
Mica	None	Common
General appearance	Sandstone, fine to medium grained with brown, sandy dolomite in eastern Illinois	Interbedded or intergrading glauconitic, micaceous siltstone, shale, dolomite, and sandstone

Age

The Galesville Sandstone is generally considered to be Dresbachian in age (Howell et al., 1944; Buschbach, 1964). Buschbach suggested that the Galesville is probably equivalent to the basal beds of the Davis Formation of Missouri. Therefore, the Davis, which is largely Franconian in age, may include Dresbachian strata at the base.

In this study, the Galesville type section is revised to include fossiliferous beds at the base, previously included in the Eau Claire Sandstone of Dresbachian age. These beds may be equivalent to the dolomitic zone at the base of the Galesville in subsurface in northern Illinois. At the margin of the Galesville in Iowa, Illinois, and Indiana, the dolomitic zone appears to grade laterally into the uppermost beds of the Eau Claire. Therefore, assignment of the Galesville to the Dresbachian Stage seems warranted.

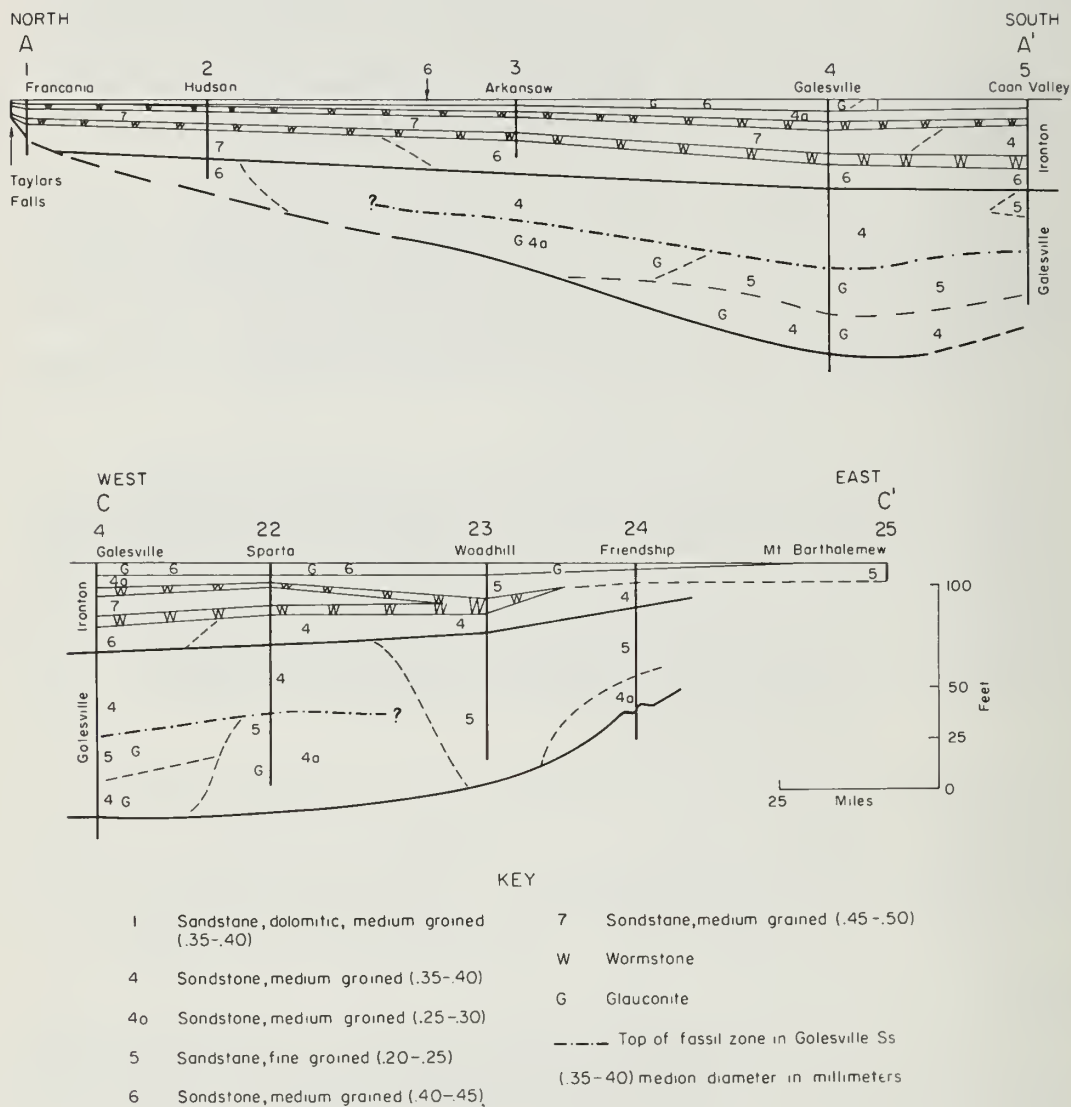


Figure 3 - Generalized cross sections of the Ironton and Galesville Sandstones in the area of outcrop. A-A' = North-south cross section along the Mississippi River from eastern Minnesota to western Wisconsin. C-C' = East-west cross section from central to western Wisconsin. (Locations shown in figure 1)

Ironton Sandstone

Definition

The Franconia Formation, as originally defined (Berkey, 1897) in Minnesota, included a "compact and thick-bedded" sandstone at the base. This basal sandstone, although different in lithology from the overlying material, was assigned to the Franconia Formation, possibly on the basis of its similar fauna. Thwaites (1923, p. 550) introduced the name Ironton Member for the few feet of hard, calcareous, coarse-grained sandstone at the base of the Franconia Formation. Ulrich (1924, p. 93) described it as the initial deposit of the Franconia Formation, and the iron-stained, fossiliferous, bench-forming beds of the basal Franconia Formation were included in the Ironton Member. The underlying worm-perforated beds called "wormstone" were included in the top of the Dresbach. Twenhofel, Raasch, and Thwaites (1935) extended the Ironton down below the wormstone beds to the fine-grained sandstones.

Study of the Franconia Formation in Wisconsin and Minnesota led Berg (1954, p. 861) to conclude that the name Ironton had "become a synonym of the Elvinia Zone" and he proposed the name Woodhill from the road cut at Woodhill (NW SW SE 3, 15N-2E, Juneau County), in central Wisconsin, for essentially the

Location of Outcrops

Cross section A-A'

1. Bluff along Lawrence Creek, 0.2 mile north of Franconia (NE SE SE 3, 33N-19 W, Chisago County, Minnesota)
2. Intersection of Wisconsin Highway 35 and Coulee Road, Hudson (SW SE NW 25, 29N-20W, St. Croix County, Wisconsin)
3. Sand pit on stream bank on County Highway N in north Arkansaw (NW NW SW 24, 25N-14W, Pepin County, Wisconsin)
4. Bluff along east side of Beaver Creek, 100 yards south of Wisconsin Highway 53 (NE NE NW 5, 19N-8W, Trempealeau County, Wisconsin)
5. Outcrop on County Highway I, 0.3 mile north of Coon Valley (SW NE NE 7, 14N-5W, Vernon County, Wisconsin)

Cross section C-C'

4. Bluff along east side of Beaver Creek, 100 yards south of Wisconsin Highway 53 (NE NE NW 5, 19N-8W, Trempealeau County, Wisconsin)
22. Roadcut on Wisconsin Highway 27, 2 miles south of Sparta (SE SE NE 34, 17N-4W, Monroe County, Wisconsin)
23. Roadcuts on Wisconsin Highway 80 at Wood Hill, 6.5 miles southwest of New Lisbon (NW SW SE 3, 15N-2E, Juneau County, Wisconsin)
24. Friendship Mound at north end of town of Friendship (NE NE NE 6, 17N-6E, Adams County, Wisconsin)
25. South side of Mt. Bartholemew, 1.4 miles west of Kingston (NE NW SW 14, 14N-11E, Green Lake County, Wisconsin)

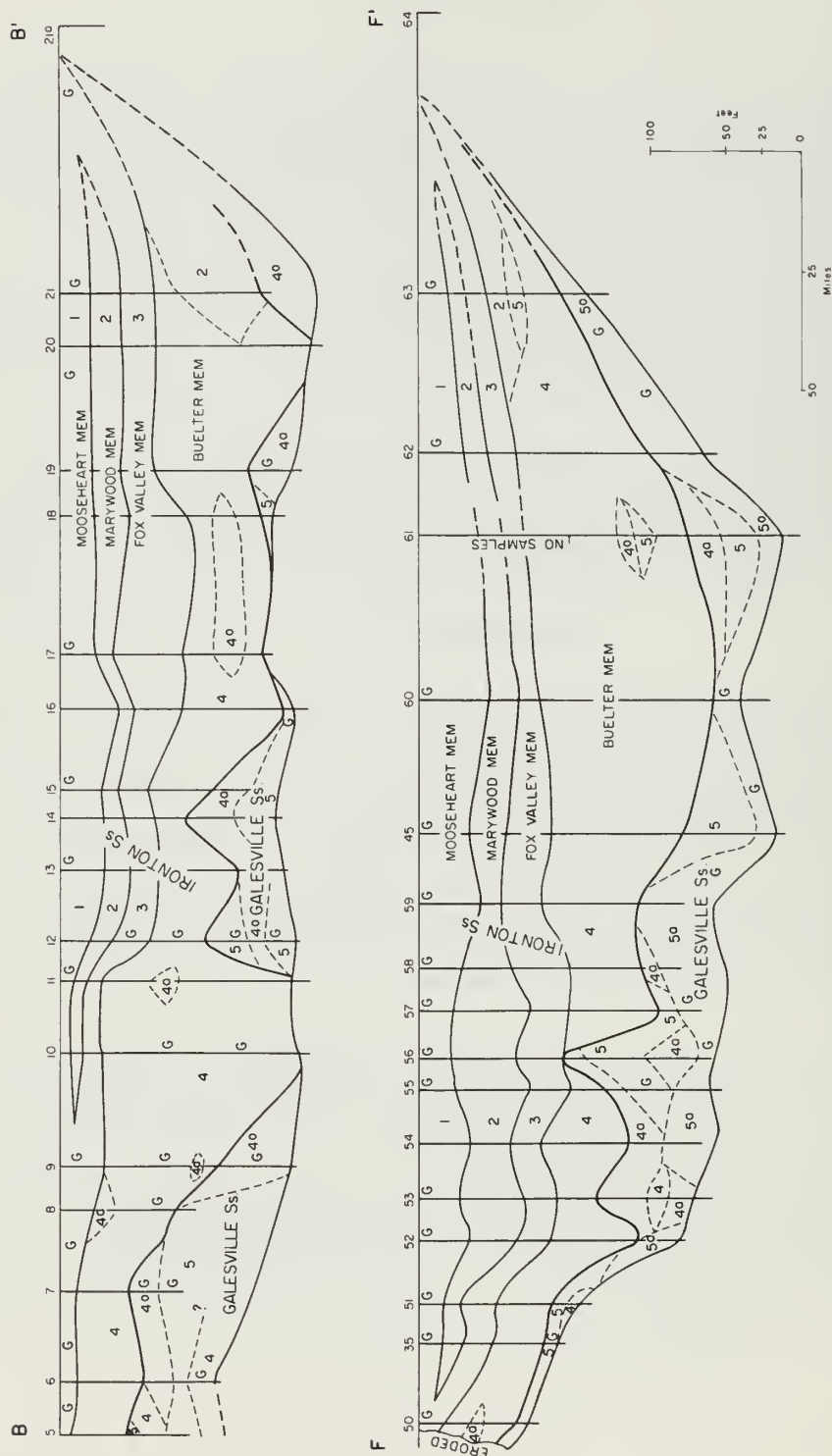


Figure 4 - Generalized north-south cross sections of the Ironton and Galesville Sandstones. B-B' = Along the Mississippi River from the outcrop area in western Wisconsin to the subsurface in western Illinois. F-F' = From eastern Wisconsin to east-central Illinois. (Locations shown in figure 1)

KEY

1	Sandstone, dolomitic, medium grained (.35-.40)	4a	Sandstone, medium grained (.25-.30)
2	Sandstone, slightly dolomitic, medium grained	5	Sandstone, fine grained (.20-.25)
3	Sandstone, dolomitic, fine to coarse grained	5a	Dolomite, sandy, brown
4	Sandstone, medium grained (.35-.40)	G	Glauconite
			(.35-.40) Median diameter in millimeters

Location of Outcrop and Wells

Cross section B-B'

5. Outcrop on County Highway I, 0.3 mile north of Coon Valley (SW NE NE 7, 14N-5W, Vernon County, Wisconsin)
6. Stoddard well (SE SE 21, 14N-7W, Vernon County, Wisconsin)
7. Viroqua Co-op. Creamery well (SE 31, 13N-4W, Vernon County, Wisconsin)
8. Mt. Sterling well (NE 26, 10N-5W, Crawford County, Wisconsin)
9. Eastman Village well (NW NW SE 14, 8N-5W, Crawford County, Wisconsin)
10. Lancaster City well (SE SE 34, 5N-3W, Grant County, Wisconsin)
11. Platteville well No. 3 (SE SW 15, 3N-1W, Grant County, Wisconsin)
12. Cuba well No. 2 (NW SE 25, 2N-1W, Grant County, Wisconsin)
13. Galenawell No. 4 (SW NW NW 20, 28N-1E, Jo Daviess County, Illinois)
14. Hanover well No. 2 (SE NE SW 9, 26N-2E, Jo Daviess County, Illinois)
15. Savanna Ordnance Depot well No. 2 (NE SE SW 2, 25N-2E, Carroll County, Illinois)
16. United Milk Products well No. 2 (NW NE NE 10, 23N-4E, Carroll County, Illinois)
17. Fulton City well No. 3 (NW NE SW 28, 22N-3E, Whiteside County, Illinois)
18. Christianson Bros. well (SW SE SE 8, 17N-1E, Rock Island County, Illinois)
19. E. A. South well (SW SW SW 30, 16N-1E, Henry County, Illinois)
20. Galesburg well No. 3 (NW NE SW 2, 11N-1E, Knox County, Illinois)
21. Abington well No. 3 (NE NE SW 33, 10N-1E, Knox County, Illinois)
- 21a. Laffey well No. 1 (SE SW NW 17, 3N-7W, Hancock County, Illinois)

Cross section F-F'

50. Pure Milk Assoc. well (SW NE NE 34, 3N-20E, Racine County, Wisconsin)
35. Genoa Junction well (SW SW SW 35, 1N-18E, Walworth County, Wisconsin)
51. Morton Chemical Co. well (NW NW SW 10, 45N-8E, McHenry County, Illinois)
52. Material Service Co. well (SE SE SE 21, 43N-8E, McHenry County, Illinois)
53. Material Service Co. well (NW SE NW 25, 42N-8E, Kane County, Illinois)
54. Howell Co. well No. 2 (SE NE NW 34, 40N-8E, Kane County, Illinois)
55. Aurora well No. 15 (NE NE NE 23, 38N-8E, Kane County, Illinois)
56. Oswego well No. 3 (SW SW NE 17, 37N-8E, Kendall County, Illinois)
57. Plainfield well No. 3 (NE NW SW 10, 36N-9E, Will County, Illinois)
58. Commonwealth Edison well No. 2 (SW SE SW 20, 35N-10E, Will County, Illinois)
59. Wilmington City well No. 2 (NW SE SW 25, 33N-9E, Will County, Illinois)
45. Illinois Central RR. well No. 1 (NW NW SW 28, 30N-10E, Kankakee County, Illinois)
60. John Taden well No. 1 (NE NE NE 11, 26N-13W, Iroquois County, Illinois)
61. Erp well No. 1 (SW NW SE 19, 24N-7E, Ford County, Illinois)
62. Webster well No. 1 (NW NW NE 17, 21N-7E, Champaign County, Illinois)
63. Shaw well No. 1 (SW SW SW 36, 16N-8E, Douglas County, Illinois)
64. Weaber-Horn Unit well No. 1 (NW NW 28, 8N-3E, Fayette County, Illinois)

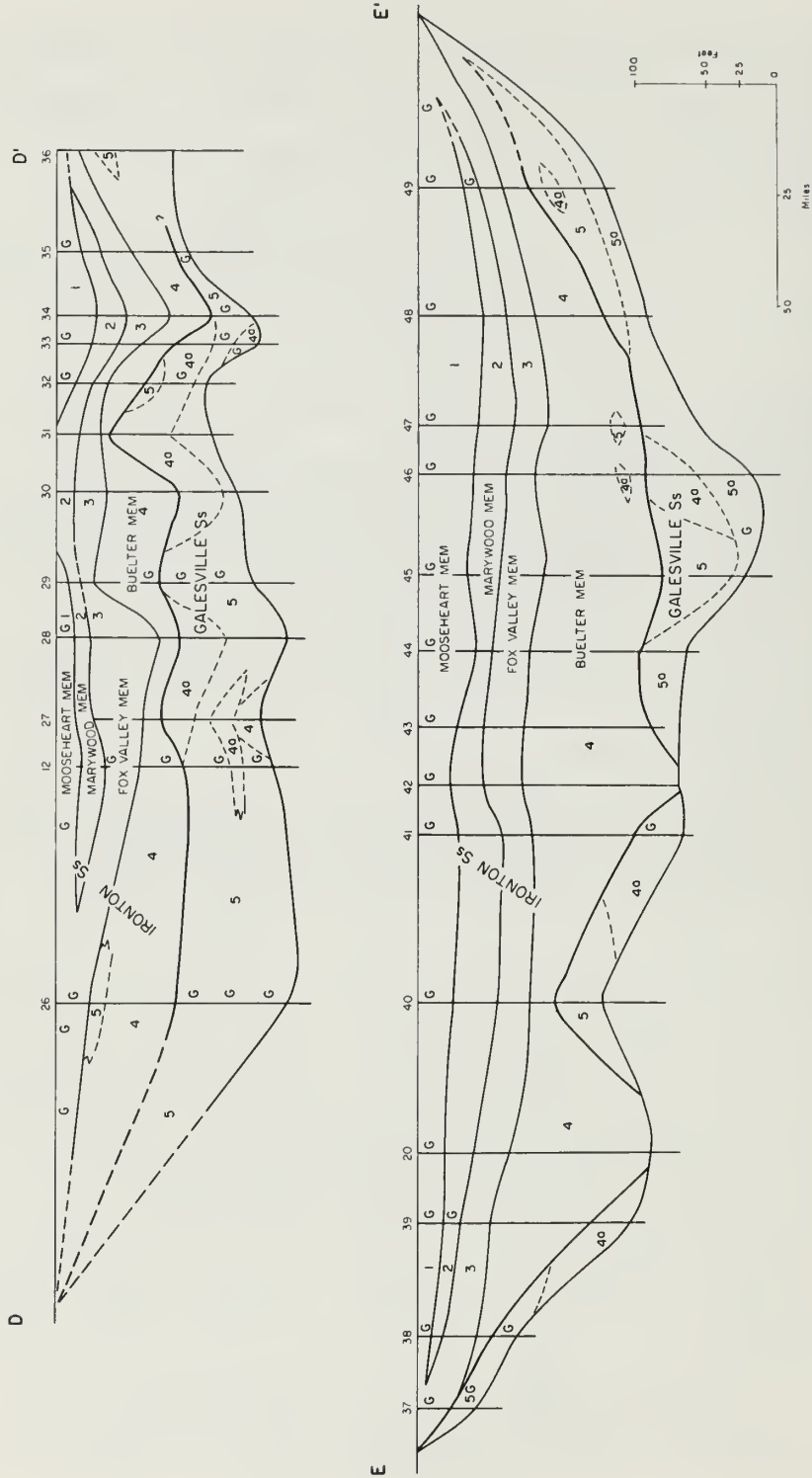


Figure 5 - Generalized east-west cross sections of the Ironton and Galesville Sandstones. D-D' = From eastern Iowa along the Wisconsin-Illinois state line. E-E' = From southeastern Iowa through central Illinois to north-eastern Indiana. (Locations shown in figure 1)

KEY

1	Sandstone, dolomitic, medium grained (.35-.40)	4o	Sandstone, medium grained (.25-.30)
2	Sandstone, slightly dolomitic, medium grained (.25-.30)	5	Sandstone, fine grained (.20-.25)
3	Sandstone, dolomitic, fine to coarse grained	5o	Dolomite, sandy, brown
4	Sandstone, medium grained (.35-.40)	G	Glauconite
			(.35-.40) Median diameter in millimeters

Location of Wells

Cross section D-D'

26. Manchester well No. 1 (NE NE NE 31, 89N-5W, Delaware County, Iowa)
12. Cuba well No. 2 (NW SE 25, 2N-1W, Grant County, Wisconsin)
27. Schullsburg well (NE NE 10, 1N-2E, Lafayette County, Wisconsin)
28. South Wayne well No. 2 (NE SE 10, 1N-5E, Lafayette County, Wisconsin)
29. Monroe City well No. 4 (SW NE NW 34, 2N-7E, Green County, Wisconsin)
30. Oxfordville well No. 2 (SE NE 24, 2N-10E, Rock County, Wisconsin)
31. Wisconsin Power and Light well No. 1 (27, 1N-12E, Rock County, Wisconsin)
32. Clinton well No. 2 (NW SW NE 8, 1N-14E, Rock County, Wisconsin)
33. Sharon well (NE NW 33, 1N-15E, Walworth County, Wisconsin)
34. Walworth well (SE NE 21, 1N-16E, Walworth County, Wisconsin)
35. Genoa Junction well (SW SW SW 35, 1N-18E, Walworth County, Wisconsin)
36. Chicago and Northwestern RR. Co. well (SE SW 9, 1N-22E, Kenosha County, Wisconsin)

Cross section E-E'

37. (SW NE NE 26, 71N-5W, Henry County, Iowa)
38. Murray Iron Works well No. 1 (NW NW NE 32, 70N-2W, Des Moines County, Iowa)
39. Monmouth well No. 1 (SW SW SW 29, 11N-2W, Warren County, Illinois)
20. Galesburg well No. 3 (NW NE SW 2, 11N-1E, Knox County, Illinois)
40. Berry well No. 1 (SW NW SE 34, 15N-6E, Bureau County, Illinois)
41. Oglesby well No. 3 (SW NE NW 36, 33N-1E, LaSalle County, Illinois)
42. Libby-Owens Ford Co. well (SW NW SW 15, 33N-3E, LaSalle County, Illinois)
43. Chicago Bridge Co. well No. 2 (SW NW NE 25, 33N-5E, LaSalle County, Illinois)
44. C. and A. RR. well (NW NW SW 9, 30N-7E, Livingston County, Illinois)
45. Illinois Central RR. well (NW NW SW 28, 30N-10E, Kankakee County, Illinois)
46. Parish well No. 1 (NW NW SW 24, 31N-13E, Kankakee County, Illinois)
47. M. A. Carsten well (NE SE SE 5, 32N-9W, Lake County, Indiana)
48. State Bank of Rensselaer well No. 1 (NE SE SE 14, 30N-6W, Jasper County, Indiana)
49. Skinner well No. 3 (NW NW 10, 28N-1W, Cass County, Indiana)

same unit previously described as Iron-ton. Although use of the name Woodhill in Illinois has been rejected (Buschbach, 1964), it is proposed that the section at Woodhill, which is in the area of the original definition of the Iron-ton, be used as a reference section. A detailed description of the section modified slightly from Berg follows:

Franconia Formation

Bed	Feet
6. Shale, glauconitic, reddish brown, weak	0.5
Iron-ton Sandstone (30.5 feet)	
5. Sandstone, glauconitic except for lower 1.5 feet, silty in upper half, brown to reddish brown, fine to medium grained, little coarse grained, friable to compact, cross-bedded, fossiliferous	4.5
4. Sandstone, white, fine to very fine grained, little medium to coarse grained, appears bimodal, cross-bedded; interbedded with 6-inch beds of sandstone, white, medium to coarse grained, little fine grained, friable, cross-bedded; few green shale partings at base	13.0
3. Sandstone, slightly silty to silty, light gray, medium to fine grained and fine to very fine grained, friable with green shale partings along many bedding planes	9.0
2. Sandstone, buff, medium to coarse grained, little fine grained, friable to compact, cross-bedded	4.0
Galesville Sandstone	
1. Sandstone, slightly silty, white, fine to very fine grained, little medium grained, friable, massive bedded, cross-bedded	59.0

Lithology

The Iron-ton Sandstone consists primarily of medium- to coarse-grained, poorly sorted, partly silty sandstone that can be traced throughout the area of outcrop. It thins from Woodhill onto the Wisconsin Arch, and at Friendship Mound (NE NE NE 6, 17N-6E, Adams County, Wisconsin) is only 19 feet thick (fig. 3, cross section C-C'). Where thinner, the Iron-ton is also much less silty, indicating deposition nearer wave base and suggesting that the Wisconsin Arch influenced sedimentation. As it is traced westward from Woodhill, it retains its general lithology. At the type locality of the Galesville Sandstone, previously described, the Iron-ton is equivalent to beds 17 to 24. Along the Mississippi Valley, it can be easily recognized until it abuts against Precambrian rocks at Taylors Falls, Minnesota (fig. 3, cross section A-A').

Individual beds in the Woodhill section have distinctive lithologies and can be traced widely. Bed 5 at Woodhill maintains its fossiliferous, glauconitic aspect and brown color, and it commonly forms a topographic bench below the weak Franconia sediments. Westward and southward it is commonly cemented with a coarsely crystalline pink-colored dolomite. In the Galesville section, it is equivalent to beds 22 to 24. The distinctive character, widespread distribution above the wormstone beds, and thickness of less than 10 feet strongly suggest that bed 5 was originally described as the Iron-ton Sandstone. The silty and shaly sandstones of bed 3, at the Woodhill section, grade westward and northward into the well known wormstones (beds 18 and 20 at the Galesville section). These wormstone beds can be traced along the outcrop as far north as Franconia, Minnesota (fig. 3, cross section A-A').

In the subsurface in Illinois, four members can be widely differentiated in the Ironton Sandstone (Buschbach, 1964). As described by Buschbach, the Mooseheart Member, at the top, consists of dolomitic and glauconitic, relatively coarse-grained, poorly sorted sandstone. The Marywood Member below consists of less dolomitic and generally finer grained sandstone than the members above and below. The Fox Valley Member consists of dolomitic, poorly sorted, medium- to coarse-grained sandstone with beds of sandy dolomite. The Buelter Member, at the base, consists primarily of medium-grained sandstone that is moderately to poorly sorted and rarely dolomitic. All the members become progressively more dolomitic southward. In this study, the base of the Fox Valley Member was found to be the most widely recognizable contact in the Ironton-Galesville sequence.

The members are well defined in the following well log of the Batavia City well No. 4, NE SE NE 22, 39N-8E, Kane County, Illinois, drilled in 1953 by J. P. Miller Artesian Well Co., sample set no. 23325, on file at the Illinois Geological Survey:

Franconia Formation

Bed	Thickness	Depth (To top)
8. Shale, slightly glauconitic, greenish gray, weak; dolomite, sandy, glauconitic, light buff, grading to sandstone, glauconitic, dolomitic, light gray, very fine to fine grained, compact	17	1125
Ironton Sandstone		
Mooseheart Member		
7. Sandstone, white, medium to coarse grained, little fine grained, rounded, frosted, incoherent grading to dolomite, slightly glauconitic at top, sandy, buff to light pinkish buff, fine to medium grained, crystalline	28	1142
Marywood Member		
6. Sandstone, partly silty, white, medium grained, little fine and coarse grained, rounded, frosted, incoherent, grading to little dolomite, very sandy, light buff, finely crystalline	45	1170
Fox Valley Member		
5. Sandstone, white, medium grained, little coarse and fine grained, rounded, frosted, incoherent, grading to dolomite, sandy, buff to light gray, finely crystalline	20	1215
Buelter Member		
4. Sandstone, white, medium grained, little coarse and fine grained, rounded, frosted, incoherent to friable	65	1235
Galesville Sandstone		
3. Sandstone, white, fine to very fine grained, subrounded, frosted, incoherent	15	1300
2. Sandstone, as above, grading to dolomite, sandy, brown, fine to very finely crystalline	15	1315
Eau Claire Formation		
1. Shale, slightly glauconitic, brown to grayish buff, weak; little siltstone, glauconitic, brown, tough	15	1330

Fauna

The name Ironton Sandstone has become synonymous with the Elvinia Zone to many geologists. Actually, this fauna is found only in the upper few

feet of the Ironton Sandstone and no fossils have been reported from the lower part of the formation. The Elvinia fauna has been described in papers by Nelson (1951), Bell, Feniak, and Kurtz (1952), and Berg (1954, p. 867) as consisting of Camaraspis convexa, Camaraspoides berkeyi, Berkeia typica, rarely Elvinia roemeri, and abundant inarticulate brachiopods. At the top of Point Bluff (SW NW NW 30, 16N-4E, Juneau County, Wisconsin), an algal structure was noted, but definite generic identification was not attempted.

Distinctive beds that have been termed "wormstone" (Twenhofel and Thwaites, 1919, p. 622) are common to the Ironton Sandstone. These beds are uniform in thickness over distances of up to 100 miles but are much siltier than the adjacent beds with which they have very sharp contacts. The sand grains vary greatly in size, and bimodal distribution is common. The wormstone beds are less resistant to weathering than the overlying sandstone ledges that characteristically overhang them.

Locally, at the base of the wormstone beds, worm borings extend several inches into the underlying beds. The borings are filled with sediment like that in the wormstone beds. Cambrian worms are considered to have been primarily marine (Howell, 1957, p. 805-806; 1962, p. W145).

Stratigraphic Relations

The contact between the Ironton and Galesville Sandstones is easily recognized in the outcrop area. The change is usually abrupt, as at Woodhill and Galesville, where there is relief of 1 or 2 inches along the contact. No evidence of reworking of the upper beds of the Galesville was seen. Locally, along the Mississippi River, this change is gradational through a thickness of 1 or 2 feet.

In subsurface, the differentiation of the Ironton and Galesville Sandstones generally is more difficult, and in some areas, as in parts of western Illinois, it is doubtful that a consistent boundary can be followed. The relatively poor sorting of the sand in the Buelter Member at the base of the Ironton is not as readily recognized in well samples as in outcrops, so that the major basis for separation is the finer and more uniform grain size of the Galesville. Differentiation of the formations on this basis, which is consistent with criteria used in the outcrops, indicates a considerable relief in the contact between the formations and a general southward thickening of the Ironton at the expense of the Galesville. In places, Galesville-type sandstone is entirely lacking, and it is assumed that the Ironton rests directly on the Eau Claire. Although these criteria maintain the lithologic distinctiveness of the Galesville, the nature of the contact between the sandstones cannot be established by the well samples, and it is possible, if not probable, that some of the apparent relief results from facies changes in the Galesville, in the Buelter Member, or in both.

Throughout the outcrop area there is an abrupt change in sedimentation from the medium- to coarse-grained, slightly glauconitic sandstones of the Ironton Sandstone to the highly glauconitic, fossiliferous, fine-grained sandstones and siltstones of the Franconia Formation. Not only is there a change in lithology at the contact of the Ironton and Franconia Formations, but at Lone Rock, Wisconsin (SW SE SE 13, 8N-2E, Iowa County), Berg (1954, p. 880-881) describes an outcrop where locally the Ironton Sandstone was eroded and the Franconia Formation rests on the Galesville Sandstone.

In the subsurface, the following criteria were used to separate the Franconia Formation from the underlying Ironton Sandstone:

	Franconia Formation	Ironton Sandstone
Grain size	Very fine-grained sandstones in the north grading to siltstone and shale to the south	Medium grained with varying amounts of fine and coarse grained
Dolomite	Present as silty or argillaceous dolomite grading to siltstone or sandstone; very finely to finely crystalline	Present as discrete dolomite beds or cementing sandstone; fine grained, crystalline
Glaucconite	Very glauconitic; glauconite is very fine to fine grained	Slightly glauconitic; glauconite is medium to fine grained
Color	Variable, with shades of green or gray common	Red to pink to brown

Age

The Ironton Sandstone is assigned to the Franconian Stage because the Elvinia fauna is present in the uppermost beds. Although fossils are lacking in lower beds, the continuity of the Ironton members favors inclusion of the entire formation in the Franconian Stage. The Ironton is equivalent to part of the Davis Formation of Missouri, which also contains the Elvinia fauna.

STRUCTURE

A structure map on the top of the Ironton Sandstone in Illinois, Indiana, and Iowa (fig. 6) was made by projecting the structure of the Galena Dolomite, which is based on a large number of wells, downward to the Ironton, using a thickness map of the interval from the Galena to the Ironton. In Wisconsin, and locally in Illinois, the structure contour lines were drawn solely on the basis of wells that penetrated to the Ironton Sandstone.

The structure map of the Ironton shows a broad uplift, the Wisconsin Arch, extending from south-central Wisconsin into northern Illinois. In northeastern Illinois, the Kankakee Arch is a broad structural feature with a series of northwest-southeast-trending folds, but in northwestern Indiana it is narrower and more sharply defined; it separates the Illinois and Michigan Basins. In western Illinois and southeastern Iowa, the broad Mississippi River Arch separates the Illinois and Forest City Basins. The LaSalle Anticlinal Belt consists of anticlines arranged en echelon, and it extends for over 200 miles from north-central to southeastern Illinois. The north end merges into the east-west-trending Ashton Arch and the Savana-Sabula Anticline, which extends into eastern Iowa. The Sandwich Fault Zone extends in a northwest-southeast direction across northern Illinois. Faulting at Des Plaines, northwest of Chicago, is complex and has no apparent relationship to regional structure (Emrich and Bergstrom, 1962, p. 961-962.)

THICKNESS

The thickness of the combined Ironton and Galesville Sandstones (fig. 7) ranges from a feather edge at the formation limits to more than 250 feet southwest of Chicago, in Kankakee, Iroquois, and Livingston Counties, Illinois.

In western Wisconsin and eastern Minnesota, the Ironton and Galesville Sandstones abut against Precambrian rocks. They thicken gradually southward to the area of maximum thickness. From there they thin rapidly but uniformly to the east, south, and west. The zero line on the thickness map indicates the farthest extent to which sand can be traced. As the units thin, they grade to sandy dolomite. The regional variations in thickness are gradual.

The sandstones thin along the Wisconsin Arch in south-central Wisconsin and north-central Illinois. In eastern Wisconsin, the Ironton and Galesville Sandstones thin to less than 50 feet. In places, they are entirely removed by pre-St. Peter erosion.

In a broad area, the base of the Fox Valley Member of the Ironton is the base of a zone that is more dolomitic, less friable, and less permeable than the underlying zone, which consists of the Buelter Member of the Ironton as well as the Galesville Sandstone. Because of their differences in water-bearing characteristics, thickness maps of the two zones were prepared (figs. 8, 9).

The lower zone has a maximum thickness of about 150 feet in east-central Illinois and in southwestern Wisconsin. It thins in western Illinois, in southeastern Wisconsin, and over the Wisconsin Arch.

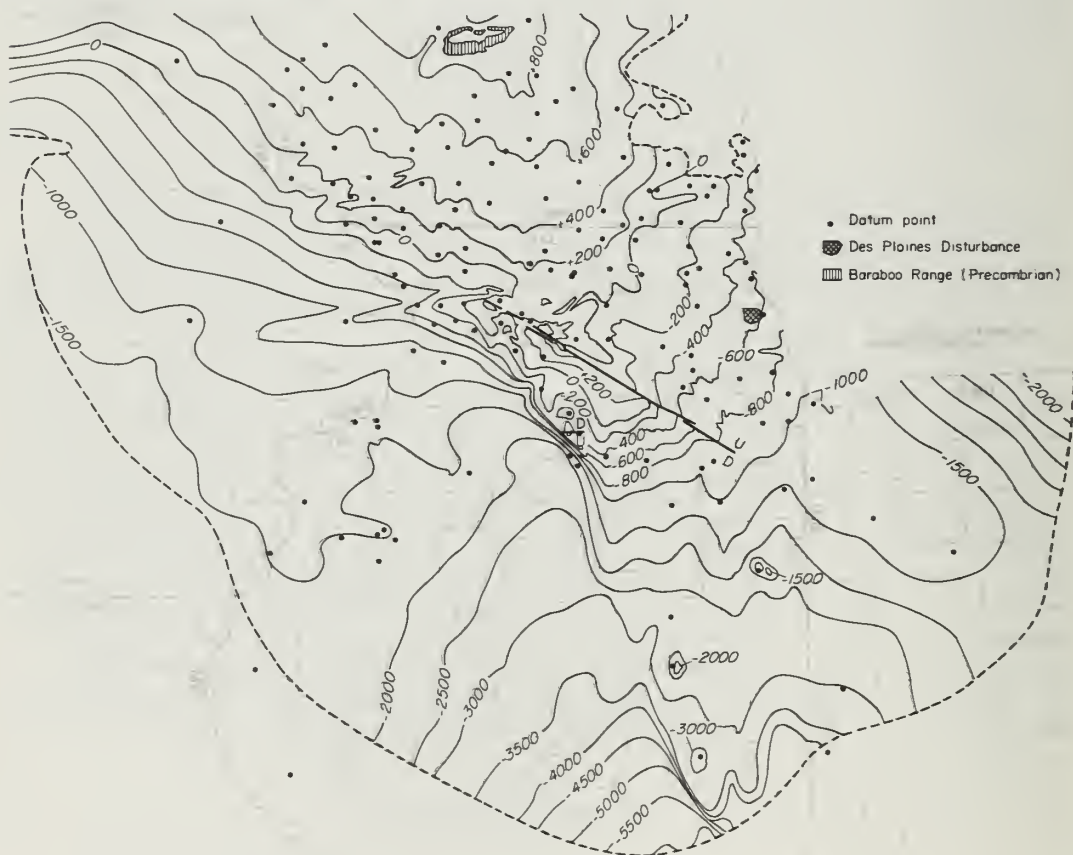


Figure 6 - Structure map of the top of the Ironton Sandstone.

The upper zone (fig. 9) has a maximum thickness of slightly over 100 feet in the vicinity of Chicago.

DOLOMITE DISTRIBUTION

Dolomite in the Ironton and Galesville Sandstones (fig. 10) ranges from zero to over 80 percent. All the carbonate mineral is dolomite. The amount of dolomite was determined by visual estimation under a binocular microscope (Emrich and Wobber, 1963) for each of the well samples studied in detail. In outcrops along the Mississippi River, in southwestern Wisconsin, and east of the Baraboo Range, dolomite is present only as a cement at the top of the Ironton Sandstone. In the subsurface of southern Wisconsin, eastern Iowa, and northern Illinois, the amount of dolomite increases gradually to the area of maximum thickness. In this area, the dolomite is primarily in the Ironton Sandstone, except in the southern part where basal beds of the Galesville are dolomitic. South of this area, the dolomite content increases rapidly in both Ironton and Galesville Sandstones until it reaches its maximum at the southern limit of the formations. The dolomite content increases

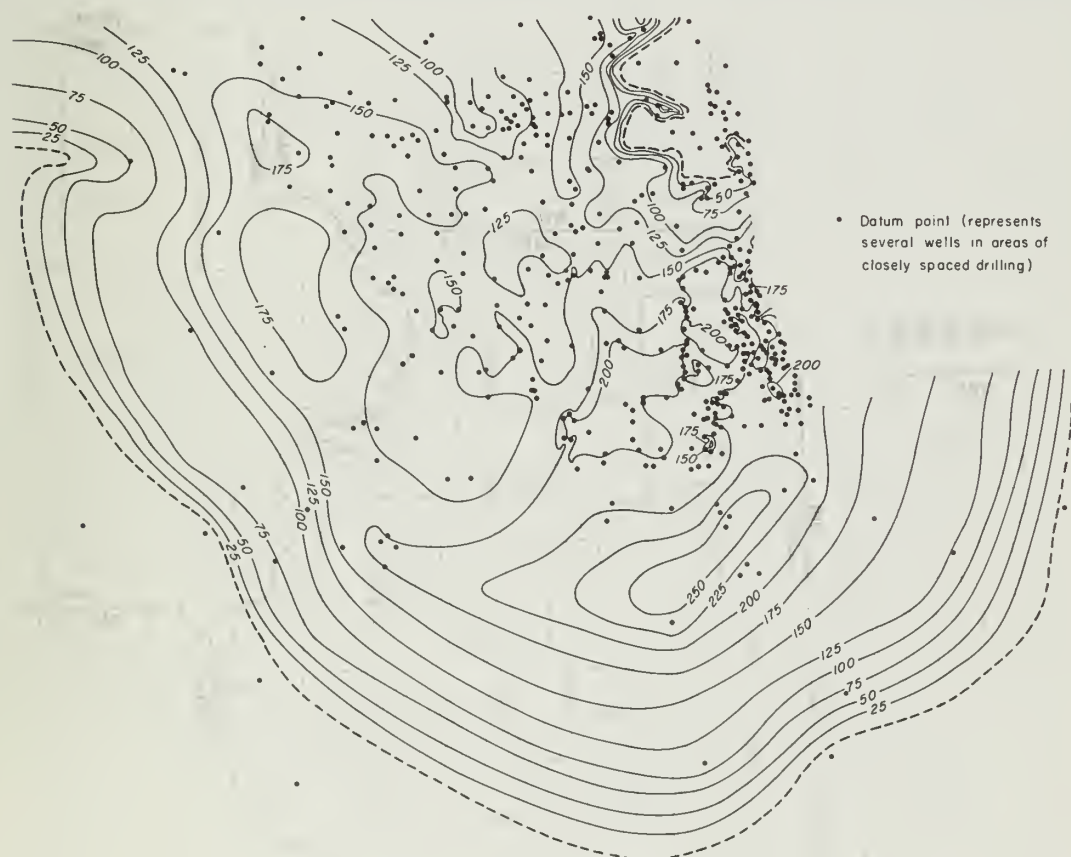


Figure 7 - Thickness of the Ironton and Galesville Sandstones.

eastward, and in Indiana and eastern Illinois it is much larger than in western Illinois and Iowa.

Cores from wells in northern, eastern, and east-central Illinois and northern Indiana show that the dolomite not only cements the sandstone but also forms discrete beds of dolomite. The Fox Valley Member of the Ironton contains thin beds of pure, very finely crystalline dolomite (pl. 1A). Flat and edgewise pebble conglomerates (pl. 1B) are present in the sandstone and dolomite. Some of the pebbles are up to 3 inches in length with slightly rounded ends.

In southeastern Wisconsin and extreme northern Illinois, the dolomite is dominantly red to pink, but in central Illinois and Indiana it is most commonly brown (fig. 11). Between these two areas, the dolomite is buff to light gray, locally pink or brown. This color pattern is repeated in the overlying Franconia Formation and the upper 20 feet of the underlying Eau Claire Formation and appears to be of primary origin.

In the Chicago area and southward, lenses of fine to very finely crystalline, dark brown dolomite with minor amounts of a very fine-grained sandstone are present at the base of the Galesville. These lenses of dolomite unite to form one continuous bed, which thickens southward to a maximum known thickness of 50 feet in east-central Illinois (Champaign County, fig. 4, cross section F-F').



Figure 8 - Thickness of the lower zone of the Ironton-Galesville Sandstone.

PETROLOGY

Many local, and a few comprehensive, regional petrologic studies have been made of the Cambrian sandstones of the Upper Mississippi Valley (Potter and Pryor, 1961, p. 1200, 1201). A large number of heavy mineral studies were made in the 1930's (Becker, 1931; Graham, 1930; Ockerman, 1930; Pentland, 1931; Raasch, 1935; Tyler, 1936; Wannemacher, Twenhofel, and Raasch, 1934; and Wilgus, 1933) as well as the 1950's and early 1960's (Berg, 1951; Driscoll, 1959; and Hamblin, 1958, 1961). A unique characteristic of the Cambrian sandstones is the presence of large amounts of authigenic feldspar (Goldich, 1934; Tester and Atwater, 1934; Berg, 1952; and Hamblin, 1958).

Oolites

Round structures identified as oolites and pellets are scattered through the dolomitic beds. The pellets may be oolites that have lost their distinctive banding. The oolites are poorly preserved; the individual bands were partially destroyed by dolomitization. The oolites are found in beds associated with medium- to coarse-



Figure 9 - Thickness of the upper zone of the Ironton-Galesville Sandstone.

grained sand or in beds of sandy dolomite. Generally, the higher the sand content, the larger the oolites and pellets.

The frequency of occurrence of oolites was estimated by recording the percentage of samples with oolites in each of the wells studied in detail (fig. 12). Frequency ranges from zero to over 50 percent in western Illinois and near the Ironton margin in west-central Indiana. The highest concentrations of oolites are found in western and eastern Illinois. A local decrease in abundance in the area of maximum thickness of the sandstone may reflect a decrease in turbulence of the water. In the region of the Wisconsin Arch, the decrease in oolite content reflects the presence of little or no carbonate.

Mineral Composition of the Sandstones

Petrographic studies of the Ironton and Galesville Sandstones were made on samples from selected outcrops and cores. All samples were treated with hydrochloric acid to remove dolomite and iron staining. The samples were sieved and the sand in the very fine, fine, and medium size ranges (0.062-0.50 mm) was separated for analysis. Light and heavy minerals were separated with bromoform (spe-



Figure 10 - Carbonate percentage map of the Ironton-Galesville Sandstone.

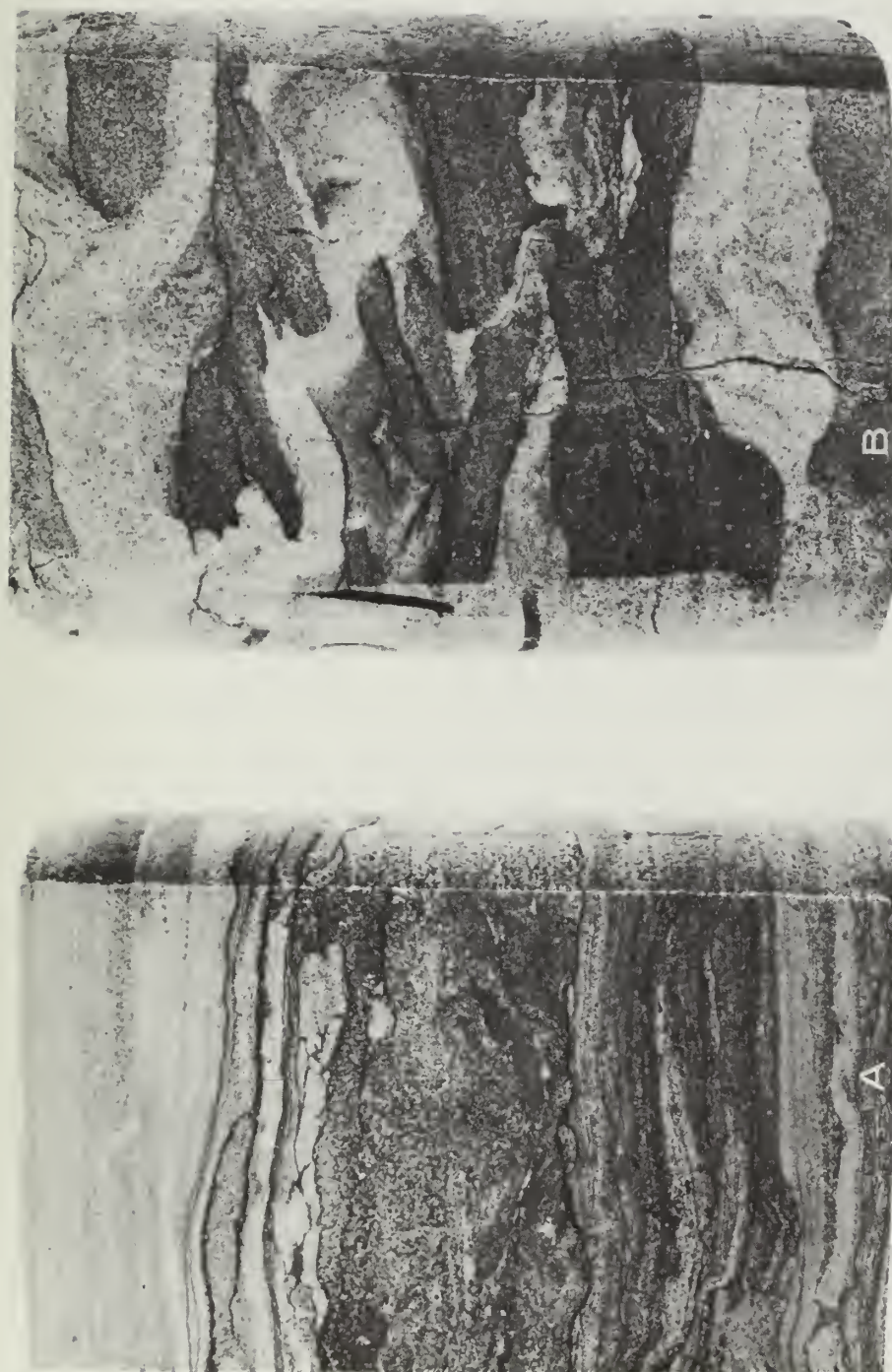


Plate 1 - Core samples of Iron-ton Sandstone. A. Thin-bedded dolomite near the top of the Iron-ton Sandstone. B. Dolomite pebble conglomerate from the Iron-ton Sandstone.

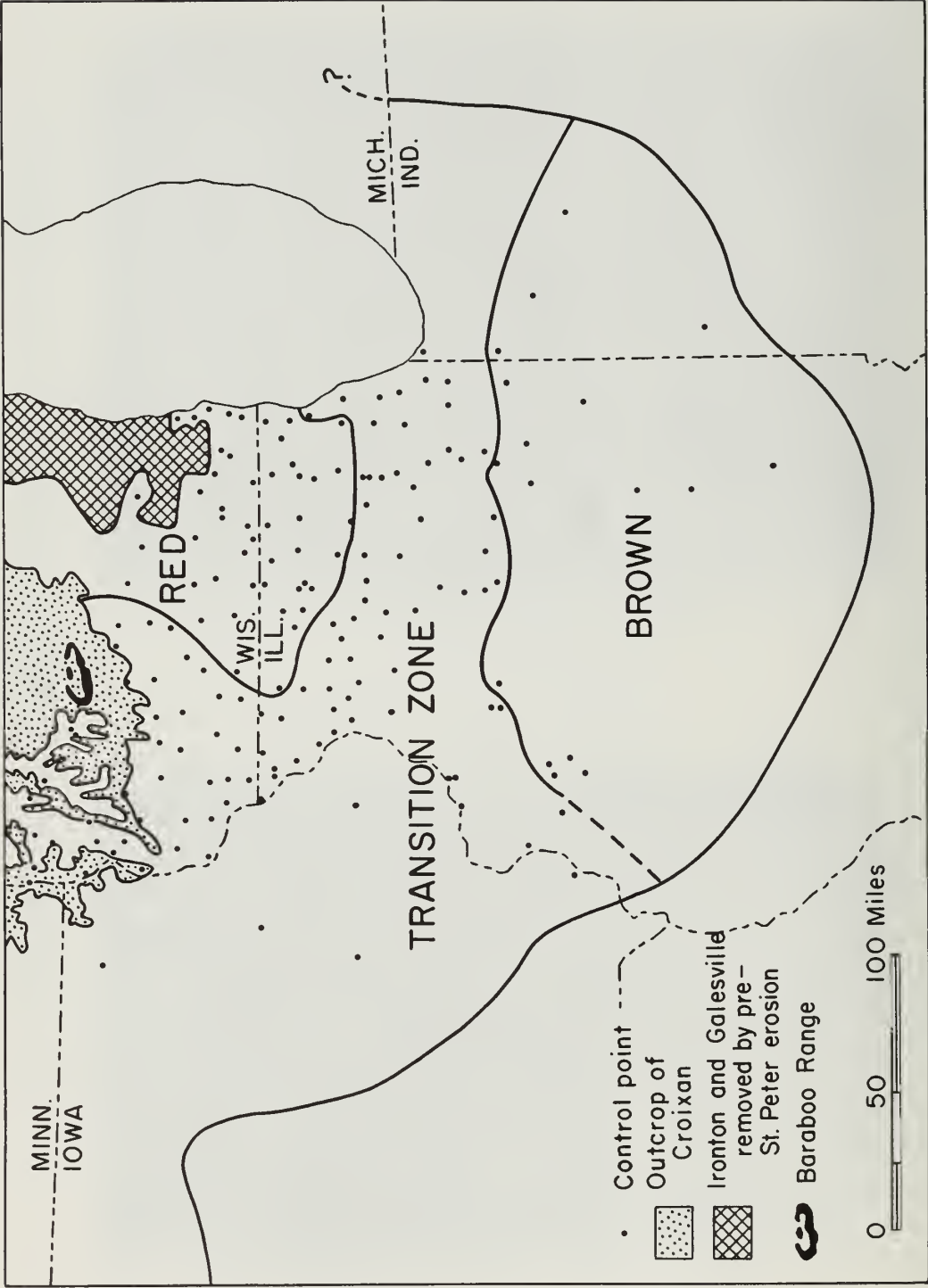


Figure 11 - Color of the carbonate of the Ironton-Galesville Sandstone.

cific gravity 2.87). Light minerals were mounted on slides, etched with hydrofluoric acid, and stained. Two hundred grains per slide, on 58 slides, were counted to determine gross mineralogy. In addition, eight thin sections were prepared from outcrop and subsurface samples and point-count percentages of the constituents were estimated. Heavy minerals were mounted on slides and a line count made until 100 monopaque grains were counted.

Light Minerals

Grain counts of the prepared slides of light minerals show that quartz constitutes over 99 percent of the sand fraction. Only minor amounts of feldspar, chert, and glauconite were present. To supplement this information, 200 grain point-counts were made of eight thin sections (table 1). Quartz makes up 83 to 99.5 percent of these sandstones and averages 95.2 percent. Secondary overgrowths were noted only on slide 7, where they were common. The individual grains are of various sizes and exhibit a moderate degree of rounding (33 to 59 percent).

The following varieties of quartz were counted in each thin section: (1) unstrained quartz, 92 to 98 percent, (2) strained quartz, 1 to 7 percent, and (3) polycrystalline quartz, 0 to 5 percent.



Figure 12 - Percentage of samples with oolites in the Ironton and Galesville Sandstones.

In the Ironton and Galesville Sandstones, feldspar averages 1.1 percent and is as much as 5 percent. The highest percentage was from a wormstone bed. Microcline, plagioclase, and orthoclase feldspar were recognized. The presence of rounded to subrounded grains indicates a detrital origin for part of the orthoclase and all of the microcline and plagioclase. Authigenic orthoclase occurs as rhombic overgrowths on the detrital grains, especially on microcline, in all thin sections where feldspar was present. All X-ray analyses of the clays indicated feldspar, and feldspar apparently is present in all the sandstone, at least in minor amounts.

Matrix, consisting of silt and clay, is as much as 3.5 percent and averages 1.5 percent.

Glaucinite (?) makes up 17 percent of one outcrop sample from the upper, brown, fossiliferous zone at the top of the Ironton Sandstone. The material consists of dense, black grains with yellow rims. Similar black material coats many of the quartz grains. Thin sections of the overlying Franconia Formation contain glauconite grains with black spots and black grains with yellow rims, similar to the grains found at the top of the Ironton Sandstone. The black grains are thought to be a weathered product of glauconite.

Detrital grains of chert, found in only one thin section, generally have a subrounded shape and exhibit a microcrystalline character under crossed nicols.

The thin section studies suggest that, in general, the nondolomitic sandstones are orthoquartzites (Pettijohn, 1957, p. 295).

TABLE 1 - THIN-SECTION ANALYSES OF THE IRONTON AND GALESVILLE SANDSTONES¹

Slide no.	Quartz	Feldspar	Chert	Matrix	Glaucinite
1	83	0	0	0	17
2	99	0.5	0	0.5	0
3	99.5	0	0	0.5	0
4	91	5	0.5	3.5	0
5	97	0.5	0	2.5	0
6	98	0.5	0	1.5	0
7	98	0.5	0	1.5	0
8	96	1.5	0	2.5	0
Average	95.2	1.1	0.1	1.5	2.1

¹ Location of thin-sections: 1. Woodhill section, Ironton Sandstone, 1 foot below Franconia-Ironton contact; 2. Woodhill section, Ironton Sandstone, 23 feet below Franconia-Ironton contact; 3. Woodhill section, Galesville Sandstone, 55 feet below Ironton-Galesville contact; 4. Wormstone in the Ironton Sandstone at the Franconia type locality; 5. Illinois Central RR. well No. 1, Ironton Sandstone; 6. Illinois Central RR. well No. 1, Galesville Sandstone; 7. Skinner well No. 3, Ironton Sandstone; 8. Skinner well No. 3, Galesville Sandstone.

Heavy Minerals

Heavy minerals generally form about 0.01 percent of the sediments and range up to only 0.07 percent by weight of the 74 samples studied. They consist of tourmaline, zircon, garnet, ilmenite, leucoxene, pyrite, and minor amounts of epidote and hornblende. Nearly all the grains are well rounded, except for garnet, which is commonly etched or pitted (table 2).

Zircon and tourmaline are the most consistently abundant nonopaque heavy minerals. They are generally present in almost equal amounts, although in some samples one will dominate greatly over the other. Zircon appears as well rounded, mostly colorless grains. Some grains are almost spherical, whereas others have an elongated shape. Only rarely do the zircon grains show their original crystal-line form. Tourmaline occurs as well rounded grains somewhat larger than the zircon. The blue, brown to light brown, light yellow, red, and greenish brown varieties are all present, with brown and light brown grains the most common.

Garnet is extremely variable in shape and size. Shapes range from irregularly angular to well rounded. Colorless grains are most common, but occasional red grains have large size and extreme rounding. Inclusions are rare. Etching tends to give the surface of the grains an irregular, hackly shape. Pitting produces a more subdued translucent appearance.

Hornblende and epidote only rarely occur in the Ironton and Galesville Sandstones. Hornblende grains are green and usually show pleochroism. Epidote is usually irregular in form and has a characteristic greenish yellow color, especially in reflected light.

Leucoxene occurs as rounded opaque grains in transmitted light, but it is white with a dull luster in reflected light. Equal distribution of ilmenite and leucoxene in both the outcrop and subsurface samples indicates that postdepositional weathering has not been important.

Pyrite is common only in the subsurface where it forms the large bulk of the opaque heavy minerals. It is of secondary origin and usually cements quartz grains. It is not included in heavy mineral percentages.

Hematite and limonite were usually removed by acid treatment. They occur in the upper 5 feet of the Ironton Sandstone, coating quartz grains.

Raasch (1935, p. 307) and Tyler (1936, p. 77) noted an absence or very low percentage of garnet in outcrops of the Galesville Sandstone. The Ironton and Franconia Formations, however, have a very high percentage. Possible equivalents of the Ironton and Galesville Sandstones along the south shore of Lake Superior also have a very low garnet content at the base and high garnet content at the top (Hamblin, 1958, 1961; Driscoll, 1959). In the present study, garnet was found in most samples, reaching a maximum near the contact of the Ironton and Franconia Formations. It does not differentiate the Ironton and Galesville Sandstones.

In western Wisconsin (Galesville section), pitted garnet is abundant in all samples, whereas everywhere else it is etched. Only at this section is much of the garnet rounded, as opposed to its usual angular shape.

The heavy mineral assemblages of the upper Eau Claire, Ironton, and Galesville Formations show a consistency that suggests similar source areas throughout their period of deposition. The excellent rounding of the zircon and tourmaline grains suggests that they are at least second generation and were derived by erosion from preexisting sandstones.

TABLE 2 - PERCENTAGE OF HEAVY MINERALS IN THE
IRONTON AND GALESVILLE SANDSTONESWoodhill Section
(NW SW SE 3, 15N-2E, Juneau County, Wisconsin)

Unit	Total in sample	Opaque	Nonopaque	Zircon	Tourmaline	Garnet	Ilmenite	Leucoxene	Hornblende	Epidote	Round garnet
Ironton											
0 - 4.5*	0.01	14	86	47	33	6	11	3	0	0	0
4.5- 8.5	0.01	11	89	43	40	6	6	5	0	0	50
8.5-12.5	0.03	15	85	48	35	2	8	7	0	0	0
12.5-17.5	0.03	13	87	34	51	1	9	5	0	0	0
17.5-21.5	0.02	6	94	69	25	0	4	2	0	0	0
21.5-26.5	0.02	6	94	65	27	2	4	2	0	0	0
26.5-28	0.01	7	93	22	63	8	3	4	0	0	0
Galesville											
28 -33	0.01	12	88	31	55	2	8	4	0	0	50
33 -38	0.01	10	90	57	30	3	3	7	0	0	33
38 -48	0.01	3	97	63	34	0	2	1	0	0	0
48 -58	0.01	22	78	46	26	2	10	13	1	2	0
58 -68	0.01	6	94	61	32	1	5	1	0	0	0
68 -78	0.01	18	82	45	34	2	5	13	1	0	0
78 -88	0.01	6	94	63	28	2	1	6	0	0	0

Friendship Mound Section
(NE NE NE 6, 17N-6E, Adams County, Wisconsin)

Ironton											
0 - 1.0*	0.01	26	74	35	22	17	13	13	0	0	22
1 - 5.5	0.01	14	86	29	11	46	3	11	0	0	40
5.5-11.7	0.01	17	83	48	31	4	9	8	0	0	40
11.7-18.7	0.01	20	80	25	52	3	10	10	0	0	0
Galesville											
18.7-23.7	0.01	19	81	36	43	2	3	16	0	0	0
23.7-33.7	0.01	21	79	45	34	0	7	14	0	0	0
33.7-43.7	0.01	18	82	50	32	0	5	13	0	0	0
43.7-53.7	0.01	11	89	65	20	5	7	3	0	0	0
53.7-63.7	0.01	18	82	27	38	17	9	9	0	0	14
63.7-70	0.01	14	76	25	60	1	5	9	0	0	0

* Feet below the base of the Franconia

TABLE 2 - Continued

P. Mathesius well No. 1
(SE SW SE 32, 35N-1E, LaSalle County, Illinois)

Unit	Total in sample	Opaque	Nonopaque	Zircon	Tourmaline	Garnet	Ilmenite	Leucoxene	Hornblende	Epidote	Round garnet
Ironton											
5*	0.01	22	78	61	6	11	11	11	0	0	0
19	0.02	10	90	31	54	5	10	0	0	0	33
50	0.04	18	82	44	25	13	13	5	0	0	0
Galesville											
139	0.01	8	92	27	52	13	6	2	0	0	0

Illinois Central RR. well No. 1
(NW NW SW 28, 30N-10E, Kankakee County, Illinois)

Ironton											
15*	0.03	67	33	7	24	2	34	33	0	0	100
46	0.02	50	50	8	38	4	20	30	0	0	14
60	0.02	12	88	46	38	1	12	0	1	2	0
78	0.02	12	88	61	25	3	6	5	0	0	0
103	0.01	13	87	56	28	3	9	4	0	0	0
138	0.01	25	75	30	40	5	10	15	0	0	0
Galesville											
159	0.01	31	69	17	45	6	25	6	1	0	11
193	0.01	8	92	52	38	2	6	2	0	0	50
207	0.01	2	98	2	93	3	1	1	0	0	0
216	0.04	3	97	52	40	5	2	1	0	0	0
221	0.01	16	84	16	67	0	14	3	0	0	0
228	0.01	10	90	28	62	0	8	2	0	0	0

Skinner well No. 3
(NW NW 10, 28N-1W, Cass County, Indiana)

Ironton											
1*	0.02	7	93	29	10	52	3	4	0	2	4
28	0.07	24	76	32	41	3	19	5	0	0	0
56	0.03	30	70	29	36	4	14	16	0	1	0
62	0.02	16	84	39	13	28	6	10	4	0	0
Galesville											
91	0.03	11	89	10	22	57	7	4	0	0	9
109	0.03	8	92	42	25	25	8	0	0	0	0
124	0.04	8	92	48	42	1	4	5	0	0	0

* Feet below the base of the Franconia

TABLE 2 - Continued

Galesville Section
(NE NE NW 5, 19N-8W, Trempealeau County, Wisconsin)

Unit	Total in sample	Opaque	Nonopaque	Zircon	Tourmaline	Garnet	Ilmenite	Leucoxene	Hornblende	Epidote	Round garnet
Ironston											
0 - 1.5*	0.05	1	99	20	37	42	1	0	0	0	61
1.5- 3.5	0.03	12	88	4	20	61	7	5	3	0	37
3.5- 6.5	0.04	23	77	11	17	49	8	14	1	0	67
6.5- 10	0.04	48	52	6	11	35	3	45	0	0	9
10 - 13	0.03	7	93	24	25	45	3	3	0	0	25
13 - 23	0.03	33	67	23	19	25	4	29	0	0	38
23 - 39	0.03	42	56	6	14	37	23	20	0	0	79
Galesville											
39 - 44.5	0.01	16	84	14	16	54	5	11	0	0	27
44.5- 48	0.01	12	88	24	24	41	5	6	0	0	70
48 - 48.5	0.02	26	74	15	10	49	1	25	0	0	20
48.5- 60.5	0.01	9	91	27	38	26	6	3	0	0	27
60.5- 66.5	0.01	8	92	25	25	42	4	4	0	0	15
66.5- 69.5	0.04	5	95	30	51	14	4	1	0	0	27
69.5- 83.2	0.01	22	78	27	29	22	4	18	0	0	36
86.2- 90.2	0.01	8	92	24	19	49	2	6	0	0	13
90.2- 93.7	0.03	19	81	22	31	28	5	14	0	0	20
93.7-112.7	0.01	17	83	25	45	13	2	15	0	0	73
112.7-114.7	0.01	22	78	26	50	8	8	8	0	0	56
114.7-127.4	0.02	52	48	16	32	5	23	20	3	1	55
Eau Claire											
127.4-129.9	0.03	32	68	8	43	2	18	13	16	0	0
129.9-139.4	0.02	30	70	18	40	4	4	25	8	1	67

G. Webster well No. 1
(NW NW NE 17, 21N-7E, Champaign County, Illinois)

Ironston											
13*	0.02	18	82	39	40.5	3	11.5	6	0	0	0
29	0.02	2	98	34	30	34	1	1	0	0	0
43	0.01	15	85	15	62.5	7.5	10	5	0	0	0
52	0.01	11	89	37.5	47	1	0	11	3.5	0	0

* Feet below the base of the Franconia

Mineral Composition of Clay

Samples of clay galls, clay laminations, and clay beds from the outcrop and subsurface were analyzed by X-ray diffraction techniques. In addition, the minus 2 micron fraction of each sieved sandstone sample was also analyzed. Composition of the clay beds and minus 2 micron fraction of the sandstones were identical.

Illite is the dominant clay mineral in every sample. Minor amounts of kaolinite are irregularly distributed throughout the area of outcrop. The very sharp kaolinite peak in some samples suggests an authigenic origin for part of the kaolinite. Chlorite was absent in all Ironton and Galesville samples, although it is common in the overlying and underlying formations. Potash feldspar was found in every sample.

Grain Size Analyses

The size frequency distributions of 133 samples of the Ironton and Galesville Sandstones were determined and the quantitative data plotted on arithmetic probability paper. The curves were compared with curves on data from Doeglas (1946), Van Andel and Postma (1954, p. 80-89), and Pryor (1960, p. 1481, 1483).

Doeglas proposed that three main types of frequency distribution curves result from sorting action during transportation. Van Andel and Postma refined the Doeglas-type curves. Both Doeglas and Van Andel and Postma dealt with recent deltaic sediments and suggested that groups of similar curves are characteristic for specific environments. Pryor applied this technique to an ancient deltaic sequence.

The sand types of the Ironton and Galesville Sandstones (fig. 13) most closely resemble the F and the F+S types of Van Andel and Postma. The F type is similar to the R type of Doeglas. Doeglas (1946, p. 33) states for the origin of the R-type curve, "continuous current. Stream-bed of rivers, strong marine currents, and surf action.... The R type occurs mainly in spots where velocity is high and the bottom is eroded. Sandy and coarser bottom material of the stream-bed of rivers which is continuously remolded, commonly has this type of curve especially in the thread of the current." Van Andel and Postma (1954, p. 89) considered the F-sands to be the "principal sand type of the upper delta...with sufficient supply of coarse and suspended material." The S type of Van Andel and Postma is a clay containing up to 50 percent silt and the F+S type is a combination of these two curves.

F-type sand is the dominant type for the Galesville and the lower part of the Ironton, but there is a minor amount of F+A type near the top of the Ironton. The interpretations of Doeglas and of Van Andel and Postma for these type curves have been based primarily on an environment "with a sufficient supply of coarse and suspended material." Relatively little suspended material was supplied when the Ironton and Galesville Sandstones were deposited, and it appears best to accept only the general depositional conditions—strong currents, area of high water velocity, and surf action—which indicate vigorous reworking of the sediments. The F- +S-type curves at the top of the Ironton Sandstone foreshadow the quieter depositional conditions of the Franconia Formation.

The median diameter, decile deviation, and coefficient of sorting were derived from cumulative size frequency curves for 133 samples of the Ironton and

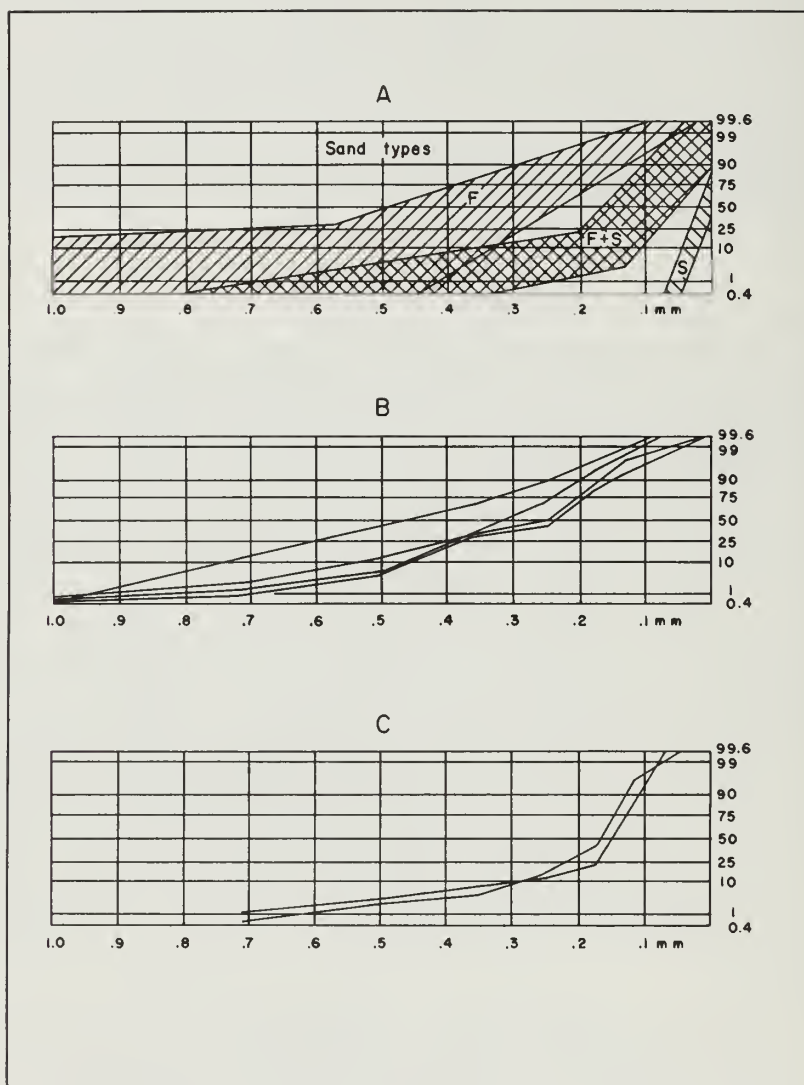


Figure 13 - Size distribution curves of the Ironton and Galesville Sandstones.
 A=Sand types of Van Andel and Postma (1954). B=Ironton and Galesville F-type sands. C=Ironton F- + S-type sands.

Galesville Sandstones. The median diameters range from 0.114 mm to 0.471 mm, very fine to medium sand, respectively. Regionally, this parameter shows no distinctive pattern, but as a general rule the Galesville is the finer grained (fig. 14). The increase in median diameters with time was caused by increasing current velocities, which diminished drastically with the beginning of Franconia deposition.

The coefficients of sorting (Trask, 1932) range from 1.16 to 2.13, which represent well sorted sand. Another more sensitive measure of sorting is the coefficient of decile deviation, which ranges from 0.510 to 1.630. Individual samples show a close correlation with the coefficient of sorting. On the basis of sieve analyses, the Ironton and Galesville Sandstones in both outcrop and subsurface are well sorted sand and have no consistent difference in sorting.

The median diameter and maximum diameter were visually estimated for each sample of all the wells studied. The average median values for each well range from $+2.47\phi$ (0.18 mm) to $+1.22\phi$ (0.43 mm), with no well defined regional pattern. Figure 15 is a map of the maximum diameters, which range from less than $+0.25\phi$ (0.75 mm) to more than -1.50ϕ (3.05 mm). Comparison of the maximum diameters shows that in over two-thirds of the wells, the largest maximum diameter is in the Ironton Sandstone, suggesting it is not sand reworked from the Galesville but new material. The largest maximum diameters (largest negative numbers) occur in northeastern Illinois and northeastern Iowa, with an uneven distribution of values throughout southern Wisconsin and northwestern Illinois. South of the area of greatest thickness of the Ironton and Galesville Sandstones in east-central Illinois, and also at the Illinois-Iowa state line, there is a rapid decrease in maximum diameters. Variations in maximum diameters reflect the maximum velocities of the currents that moved the materials to their site of deposition. The well defined areas of large maximum diameters mark areas where higher velocities persisted during deposition, in contrast to the smaller maximum diameters, which mark areas where lower velocities persisted.

SEDIMENTARY STRUCTURES

Sedimentary structures common in the Ironton and Galesville Sandstones are cross-bedding, ripple marks, clay galls, mud cracks, pebble conglomerates, and load casts.

Cross-Bedding

Cross-bedding is the most abundant and most useful of the sedimentary structures for determining the direction of sediment transportation. Cross-bedding data from the Cambrian sediments of the Upper Mississippi Valley (Hamblin, 1958, p. 84-86, 106; Farkas, 1960; Hamblin, 1961; Potter and Pryor, 1961, p. 1220-1221) indicate sediment transport and paleoslope to the south, except in northern Michigan.

At each outcrop, 10 random measurements were taken of the direction of the maximum dip of the foreset beds, the angle of maximum dip, and the thickness of the sedimentary unit. Where possible, outcrops were spaced at 6 mile intervals, but a paucity of outcrops in certain areas made wider spacing necessary. Altogether, 1284 observations were obtained from 143 outcrops in Wisconsin and Minnesota. Of these, 902 observations from 96 outcrops were in the Galesville Sandstone and 382 observations from 47 outcrops were in the Ironton Sandstone.

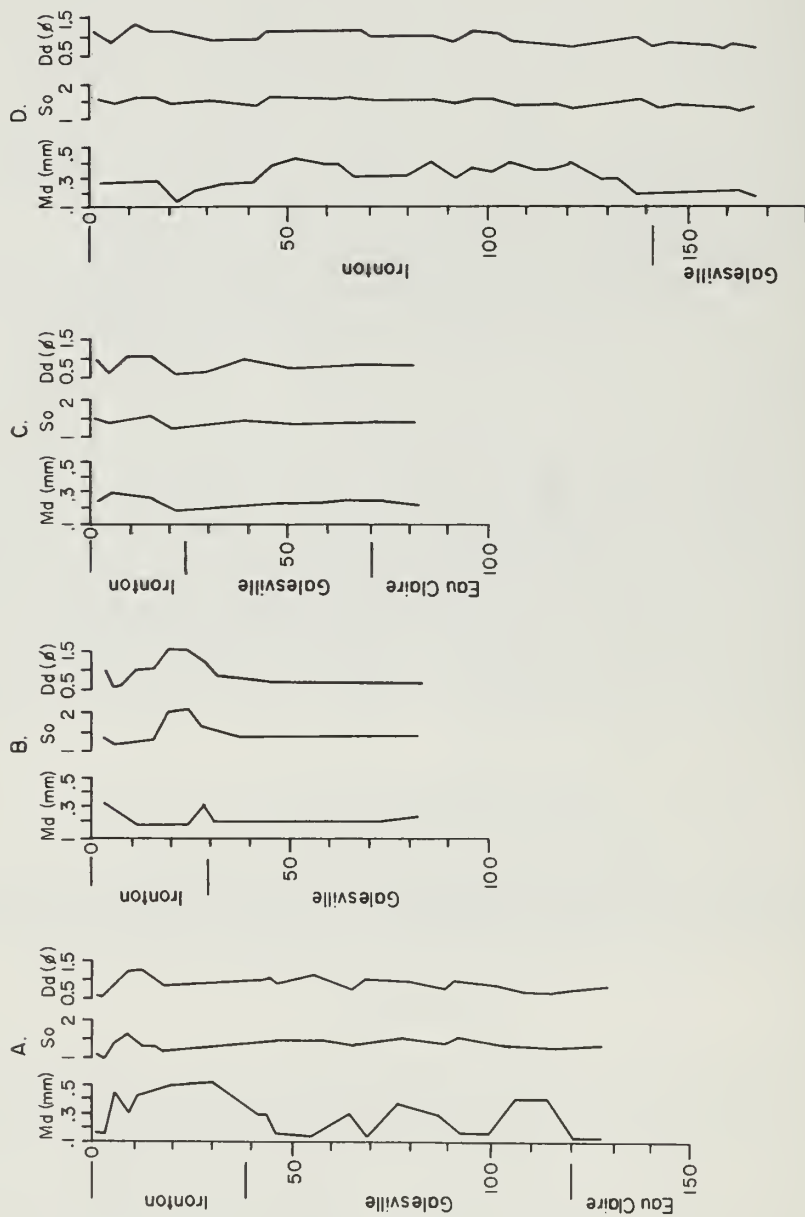


Figure 14 - Median diameter, sorting, and decile deviations of the Ironton and Galesville Sandstones.

Cross-bedding in the Ironton and Galesville Sandstones is primarily of the trough type or Nu type of Allen (1963, p. 107), with minor amounts of the planar type of McKee and Weir (1953, p. 385), or the festoon type of Pettijohn (1962, p. 1472). A cross-bedded unit usually has two or more sets.

The foreset laminations commonly are tangential to the underlying strata and have a slight wedge shape. Dips of the foreset strata range from 1 to 39 degrees and average between 8 and 16 degrees (fig. 16A). Clay galls are common along the foreset strata and, in places, can be traced to a nearby shale bed. Thicknesses of the cross-bedded units range from 1 to 144 inches. The average thickness of the units is about 4 inches (fig. 16B).

The grand mean for the cross-bedding direction in the Ironton Sandstone (fig. 17 and table 3) is 71 degrees and is not significant. The wind rose diagram shows random distribution. In northwestern Wisconsin, the 96 observations at 11 outcrops have a wind rose that shows a strong northeastern orientation. The remaining 286 observations from 36 outcrops of the Ironton Sandstone have a wind rose diagram that shows only a slight tendency toward a southern orientation.

For the Galesville Sandstone, the grand mean is 224 degrees and is significant above the 0.995 level (fig. 18). The wind rose diagram shows a southwestern orientation with much local variation.

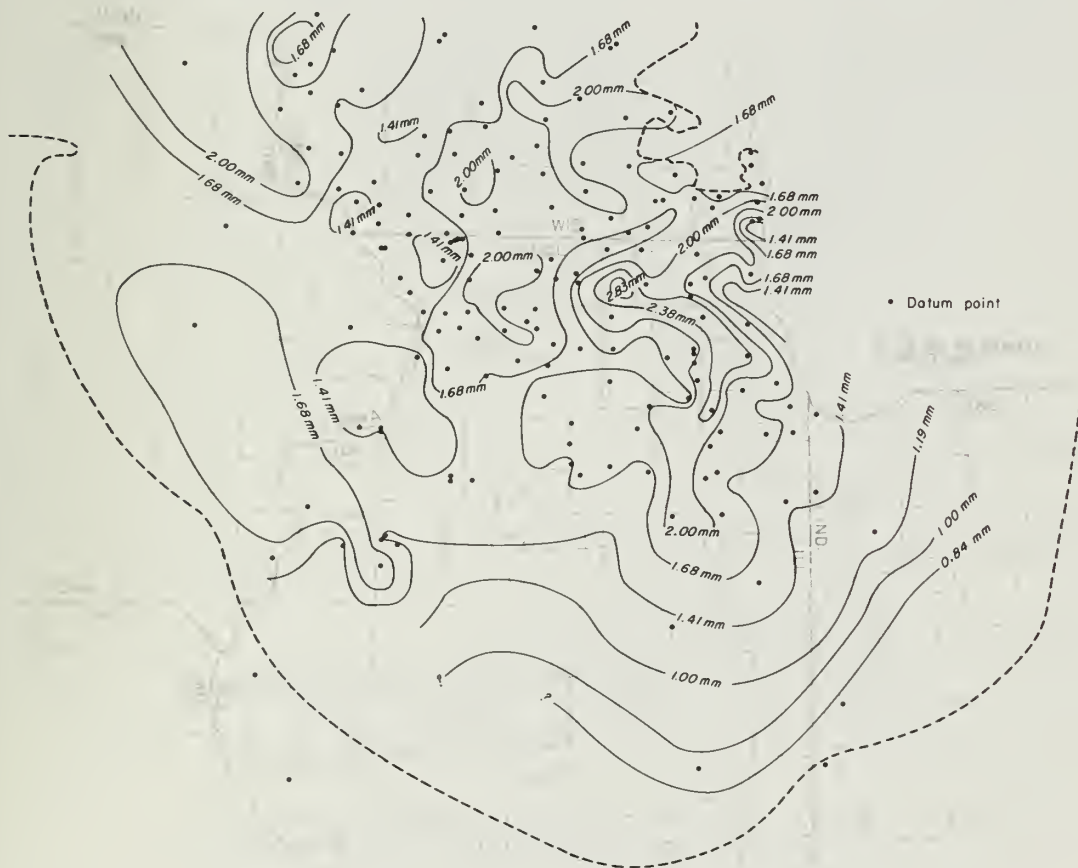


Figure 15 - Maximum diameters of sand grains in the Ironton and Galesville Sandstones.

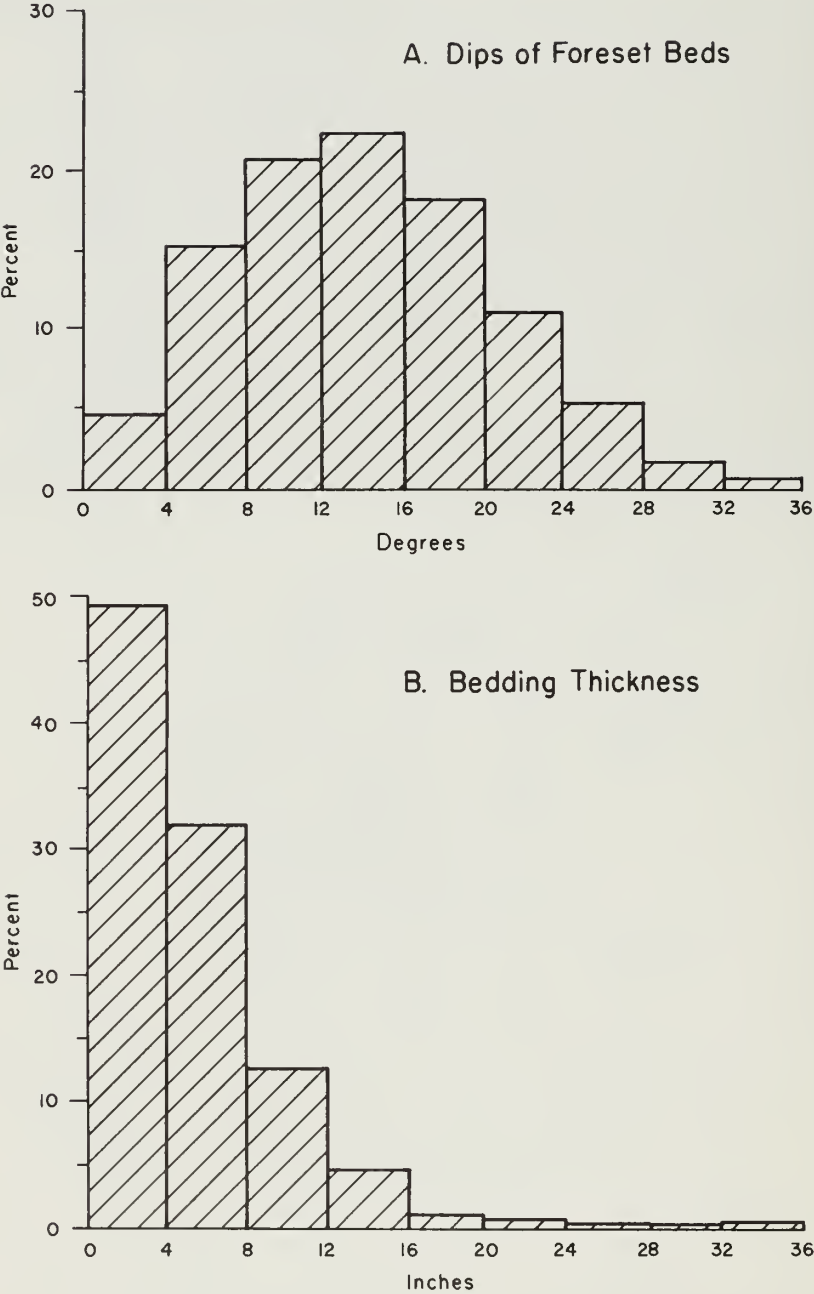


Figure 16 - Frequency distribution of (A) dips of the foreset beds and (B) thickness of cross-bedded units of the Ironton and Galesville Sandstones.

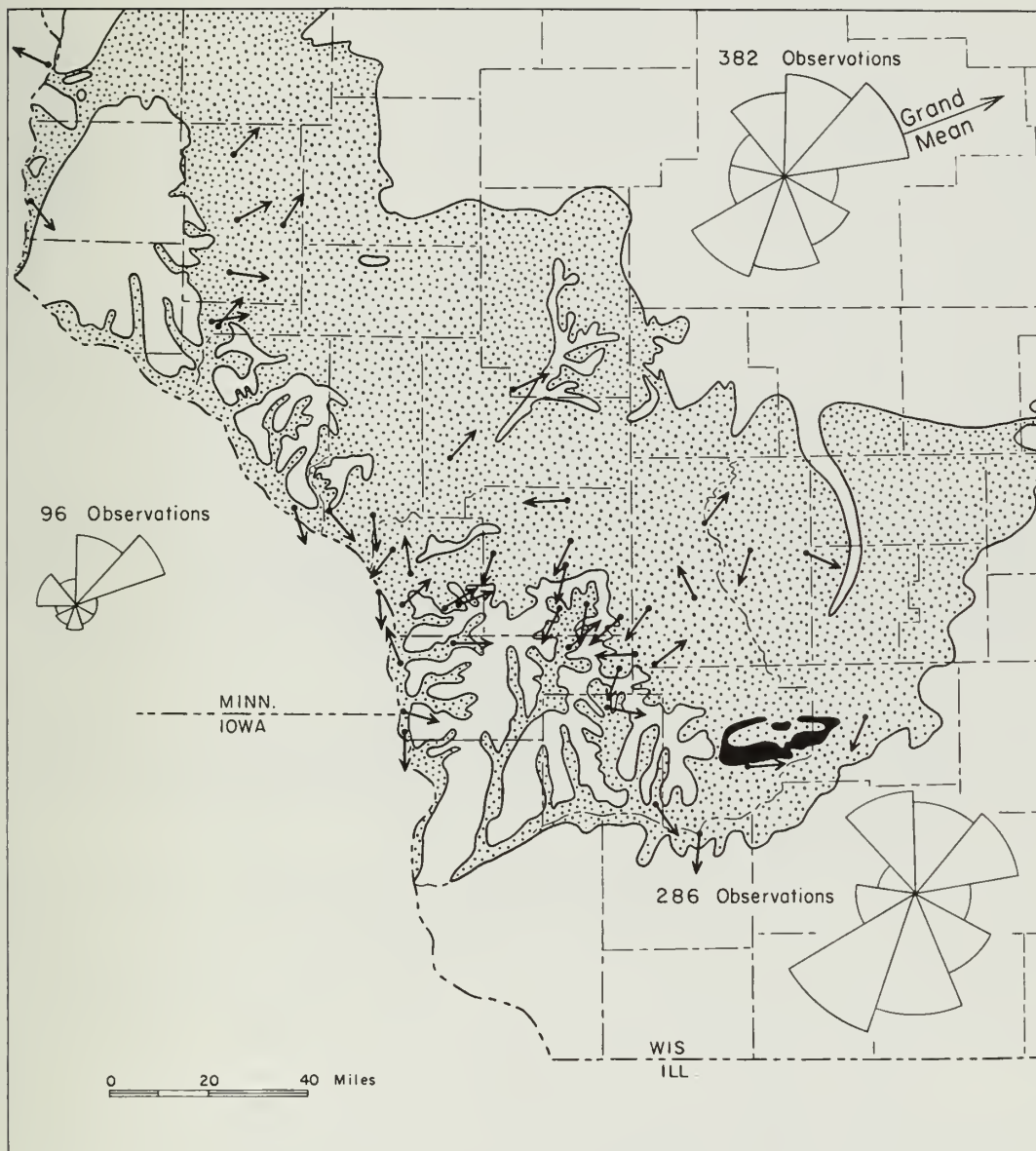


Figure 17 - Cambrian outcrop area showing average direction of cross-bedding in the Ironton Sandstone.

TABLE 3 - SUMMARY OF CROSS-BEDDING DATA OF THE IRONTON AND GALESVILLE SANDSTONES OF THE UPPER MISSISSIPPI VALLEY

Unit	Class interval									Total	Mean
	0-40	41-80	81-120	121-160	161-200	201-240	241-280	281-320	321-360		
Ironton	52	64*	27	37	49	55	28	27	43	382	71
Galesville	111	82	86	88	119	130*	113	92	81	902	224
Total	163	146	113	125	168	185*	141	119	124	1284	226

*Modal class interval

In order to note the local variation of direction, one measurement was made of each cross-bedded sedimentary unit in several outcrops. The 36 measurements at the type section of the Galesville Sandstone (fig. 19) show a preferred orientation to the southwest for the total section, as do the wind rose diagrams. This indicates a constant direction of sediment transport with no significant variations from this direction during deposition of most of the Ironton and Galesville Sandstones at this outcrop.

The grand mean for all of the 1284 measurements of the Ironton and Galesville Sandstones is 226 degrees and is significant at the 0.90 level. The mean directions at different outcrops of the Galesville Sandstone show large variations, but regionally they show a significant trend to the southwest. The grand mean of the Galesville Sandstone is approximately at right angles to the Cambrian shoreline to the north.

Cross-bedding in the Ironton Sandstone is random and not significant. In northwestern Wisconsin, the means trend in an easterly direction, probably reflecting a minor western source of sediment or possibly long-shore currents. This was also noted by Hamblin (1961, p. 17) for the "Dresbach" sediments. In southern Wisconsin, the Ironton Sandstone pattern is similar to that of the Galesville Sandstone. The lack of significance of the Ironton Sandstone measurements may indicate a decrease in slope associated with more variable currents. The decrease in slope is also shown in the textural analysis.

Attempts have been made to relate the statistical variance and standard deviation of cross-bedding to the depositional environment. Pryor (1960, p. 1488-1492) noted that nonmarine fluvial sediments have cross-bedding variances ranging from 4900 to 5800 and standard deviations from 70 degrees to 76 degrees. For the marine shelf sands, the cross-bedding variances range from 7000 to 8000 and standard deviation from 84 degrees to 90 degrees. One of the examples cited for the latter was the Franconia Formation. Pryor logically assumed that "the most important factor controlling the variance and standard deviation of dispersal patterns is the amount of slope of the depositional surfaces—the greater the amount of slope, the smaller the variance and standard deviation."

Recognizing that little is yet known concerning environmental implications of cross-bedding variance and standard deviation, it is still interesting to compare

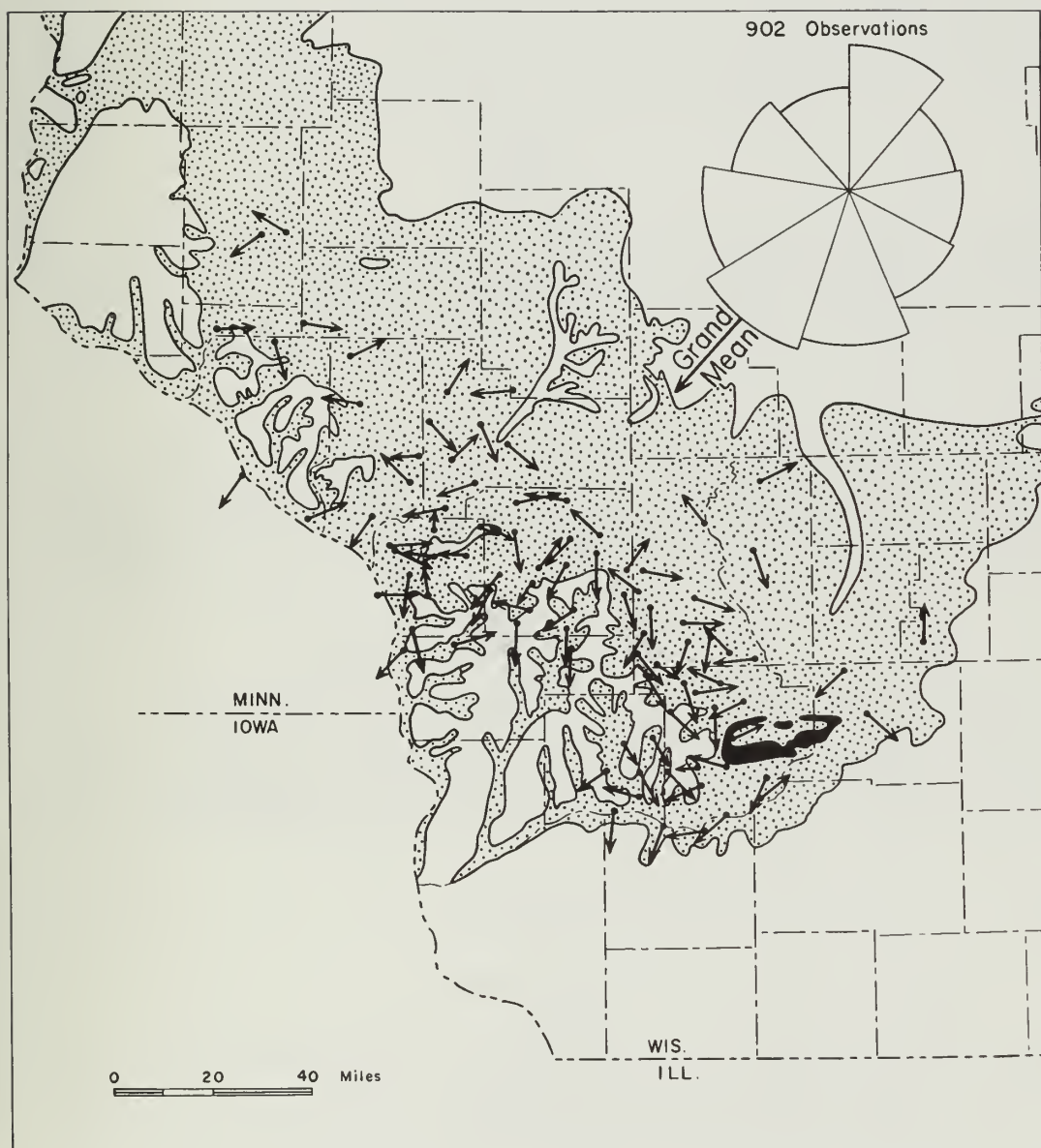


Figure 18 - Cross-bedding in the Galesville Sandstone.

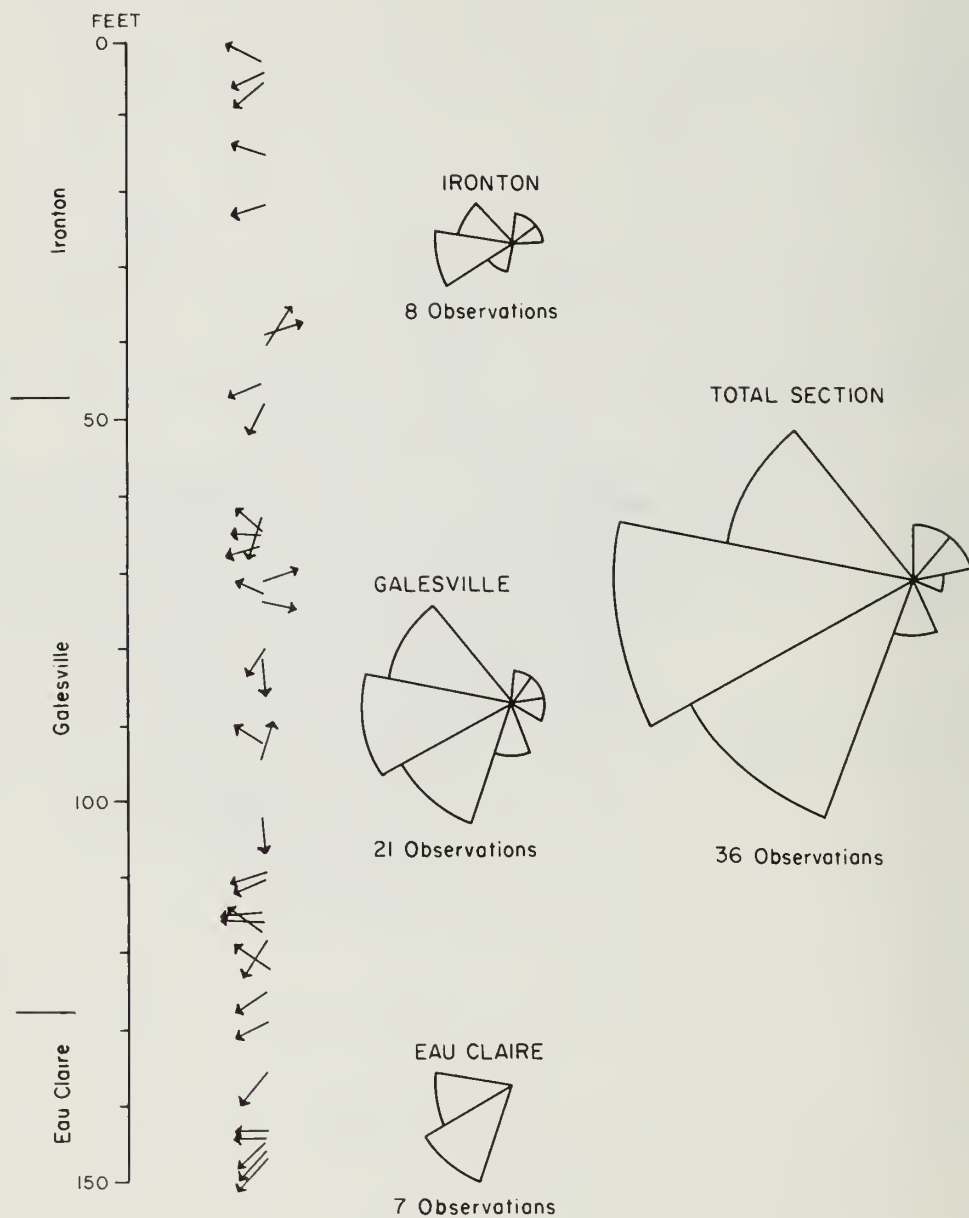


Figure 19 - Cross-bedding of the Ironton, Galesville, and Eau Claire Sandstones at the type section of the Galesville Sandstone.

the Ironton and Galesville Sandstones to the few known examples. The variance and standard deviation computed around their vector means for the Ironton and Galesville Sandstones are 12,819 and 113 degrees, respectively, which are much higher than any reported values. If these values are related to the depositional slope, then it follows that the Ironton and Galesville Sandstones were deposited under marine conditions on a slope dipping southward at an extremely low angle. The dispersal pattern of cross-bedding, therefore, is consistent with a shallow marine interpretation for the Ironton and Galesville Sandstones.

Ripple Marks

Ripple marks were recognized at only six outcrops of the over two hundred that were visited. They are not readily recognized in the friable Ironton and Galesville Sandstones. Only the symmetrical (oscillation) type was identified, with a strike approximately 90 degrees to the local cross-bedding direction.

Clay Galls

Clay galls are commonly associated with the Ironton and Galesville Sandstones and are generally found in the foreset beds of the cross-bedded units. They are normally tabular in shape, angular to subangular, up to one inch long and wide, and less than one-half inch thick. Commonly, they can be traced into a nearby shale layer.

Other Structures

In the friable sediments along the outcrop belt, other sedimentary structures are difficult to recognize. Locally, mud cracks have been tentatively identified in the area of the Wisconsin Arch. Structures that resemble load casts are common to many bedding planes. In the subsurface, where dolomite cements the sands, pebble conglomerates are present and indicate shallow marine conditions.

SEDIMENTATION

Shape of the Deposit

The Ironton and Galesville Sandstones extend as a tongue from the outcrops southward into central Illinois. This sand body has a symmetrical form with a north-south trending axis. It can be classified as a sheet sand on the basis of large areal extent compared to thickness. From the area of maximum thickness, which is south of the geographical center, the sand body thins rapidly southward to a feather edge. Other Cambrian formations in the Upper Mississippi Valley normally extend southward at least into Kentucky and also thicken in that direction.

Environment of Deposition

The presence of macrofossils establish a marine environment for the lower part of the Galesville Sandstone and the top of the Ironton Sandstone in the outcrop

area and locally in subsurface. The wormstone beds, modified by marine organisms, extend marine conditions throughout the upper half of the Ironton Sandstone. Rounded conodont fragments are present, but rare, in the one sample of the Galesville Sandstone that was checked. Although the Ironton and Galesville Sandstones are widely barren of fossils, they are considered marine because (1) there is no textural change between the fossiliferous and nonfossiliferous beds, (2) in the upper half of the Ironton Sandstone interbedded barren and fossiliferous sands are present, (3) the same sedimentary structures persist throughout the sequence and indicate a constant direction of sediment transport, and (4) petrography of the sediments remains constant. Cambrian fossils in the Upper Mississippi Valley are generally found in fine- to very fine-grained sandstones, siltstones, shales, or dolomite. The absence of fossils in the porous sandstone in the subsurface and in the middle half of the stratigraphic section in the outcrop is probably caused by destruction of the shells either during deposition of the sand in agitated water or subsequently by solution.

Thinning of the sandstones in north-central Illinois, south-central Wisconsin, and eastern Wisconsin indicates that the Wisconsin Arch, and an unnamed uplift near Milwaukee, Wisconsin, actively influenced sedimentation. Extremely uniform subsidence resulted in the constant thickness for the Ironton members. During Ironton time, the seas had their farthest northward transgression with the most widespread deposition of sands.

Sedimentary structures—pebble conglomerates, oolites, and cross-bedding—all indicate shallow-water deposition on a broad stable shelf. The abundance of oolites suggests bank conditions along the eastern and western borders of Illinois. Low concentration of oolites reflects either little or no carbonate deposition or possibly a decrease in turbulence associated with greater water depth. The increase in median diameter and siltiness of the sediments from the base upward suggests an increase in current velocity and a decrease in the reworking of the sediments. These strong currents produced sandstones that are very well sorted, with approximately uniform median and maximum diameters, as far south as central Illinois. Farther south, current velocity decreased and only finer sediments were deposited.

The stable-shelf clastic deposits are, in general, well sorted, well rounded, slightly glauconitic, sparingly fossiliferous, medium-grained, cross-bedded sands with subordinate amounts of shale and dolomite. The stable-shelf carbonate deposits consist of pure, fragmental, slightly glauconitic, cross-bedded dolomite interbedded with lesser amounts of sand. The bank deposits are represented by clean, well sorted sands of the stable-shelf type and dolomite with a high oolite content.

Provenance

The principal source contributing sediments to the Ironton and Galesville Sandstones was a terrane composed primarily of sedimentary rocks. The over-all maturity of the sediments, rounding of the quartz grains, low percentage of feldspar, and limited suite of heavy minerals consisting primarily of rounded stable minerals (tourmaline, zircon, ilmenite, and leucoxene) are believed to be indicative of sedimentary rocks that have undergone several cycles of sedimentation with a long history of transportation. The local presence of small amounts of unstable minerals (hornblende and epidote) emphasize the minor contribution directly from

crystalline rocks. The source for garnet is chiefly crystalline schists and gneisses, which are absent in northern Wisconsin and the Michigan Peninsula, and it is probable that the original source area was farther to the northeast in Canada.

The presence of minor quantities of hornblende and epidote, which exhibit no corrosive structures, suggest that intrastratal solution has not removed significant quantities of the heavy minerals from the Ironton and Galesville Sandstones.

The directional properties (figs. 17, 18) and distribution of the sandstone (fig. 10) suggest a source area to the north or northeast. Possible source areas are in northern Wisconsin and the Michigan Peninsula. Tyler (1936) and Hamblin (1958, 1961) report that the older Cambrian and Precambrian sandstones have heavy mineral suites almost identical to that of the Ironton and Galesville Sandstones. Sandstones of the Michigan Peninsula contain appreciable quantities of tourmaline and zircon and varying amounts of garnet, have a high quartz content, are well sorted, and are considered to be second-cycle sandstones (Hamblin, 1961, p. 7). These sandstones were exposed in a linear positive area, the Northern Michigan Highlands, that extended through northern Michigan to the Wisconsin Arch. These highlands had a limited areal extent and are the proposed sources of Cambrian sediments in both the Upper Mississippi Valley and the Lake Superior Basin. It seems probable that suitable source areas of sandstone were more extensive farther to the north and east into Canada.

A secondary source of sediments from the west is suggested by the directional properties and the very high percentages of garnet in the sediments in western Wisconsin. The garnets are rounded, red colored, and pitted, characteristics not found to the east or south. A possible source area to the west would be the Transcontinental Arch.

HYDROGEOLOGY

Water wells have been drilled into the Ironton-Galesville Sandstone for over 100 years, yet little detailed hydrologic information is available specifically for this aquifer. This is because wells drilled into the Ironton-Galesville also penetrate overlying aquifers and withdraw water simultaneously from several sources. In northeastern Illinois, the rocks overlying the Eau Claire Formation and subjacent to the Upper Ordovician Maquoketa Group are hydrologically interconnected and are called the Cambrian-Ordovician aquifer (Suter et al., 1959). Its principal water yielding zones are the Ironton-Galesville Sandstone, the Glenwood-St. Peter Sandstone, and locally the Eminence-Potosi Dolomite (formerly Trempealeau Dolomite) and dolomites of the Prairie du Chien Group. Similar hydrologic conditions also occur in southern Wisconsin and northwestern Illinois.

The Ironton-Galesville Sandstone is the most consistently permeable and productive aquifer in northern Illinois and southern Wisconsin. To obtain maximum yield, wells should be drilled through the full thickness of the sandstone, as the lower sandstone unit is more permeable, has less cement, and is better sorted. In most of northern Illinois, this lower sandstone unit is more than 75 feet thick (fig. 8). The upper part of the Ironton-Galesville Sandstone is less permeable because of its higher dolomite content (fig. 10).

Pumpage of sand with the water has occurred in some wells drilled into the Ironton-Galesville. Sand-pumping may occur when the well is first pumped, after it has been pumped for a period of time (ranging up to several years), or after a well has been "shot" with explosives to increase its yield. Study of the caliper

logs run on wells both before and after sand-pumping indicates that the lower sandstone unit is the more likely source of the sand, with the upper sandstone unit a secondary source. The lower sands are less cemented and thus more susceptible to caving than the upper sands.

Quantitative data on the capacity of the Ironton-Galesville Sandstone to transmit and store water are sparse. The field coefficient of permeability (P) is the rate of flow of water, in gallons per day, through a cross-sectional area of one square foot of the aquifer under a hydraulic gradient of one foot per foot at the prevailing temperature of the water. The coefficient of ~~the~~ transmissibility (T) is the rate of flow of water, in gallons per day, through a vertical strip of the aquifer one foot wide and extending the full saturated thickness under a hydraulic gradient of one foot per foot at the prevailing temperature of the water. Porosity (p) is the ratio of void space to the total volume of the rock mass. Specific capacity is the yield of a well per unit drawdown, expressed in gallons per minute (gpm) per foot.

Hydraulic coefficients are given by Suter et al. (1959, p. 49-50) for the Cambrian-Ordovician aquifer, which includes the Ironton-Galesville Sandstone. Coefficients of transmissibility (T) determined from 63 pumping tests range from 10,800 gpd per foot to 26,900 gpd per foot and average 17,400. It was estimated that 80 percent of the Cambrian-Ordovician aquifer yield (or about 14,000 gpd per foot) was from the Ironton-Galesville Sandstone. The average T for the Cambrian-Ordovician aquifer and the Mt. Simon Sandstone in the Milwaukee-Waukesha area of southeastern Wisconsin is 23,800 gpd per foot (Foley et al., 1953, p. 72).

Computed coefficients of transmissibility are fairly uniform throughout large areas. From data by Suter et al. (1959) and Foley et al. (1953), the coefficients of transmissibility of the Cambrian-Ordovician aquifer decrease in a southerly direction from an average value of 23,800 gpd per foot in the Milwaukee-Waukesha area to 15,000 gpd per foot in the area south of Chicago. Deep wells in northwestern Indiana are reported by Joseph Rosenshein (personal communication) to have small yields, indicating that the coefficients of transmissibility of the aquifer rapidly decrease south and east of Chicago.

Walton and Csallany (1962, p. 20) estimated the coefficient of transmissibility for the Ironton-Galesville Sandstone in northeastern Illinois to be less than that given by Suter et al. (1959). The Walton and Csallany study indicates that T decreases in a southerly direction from 7000 gpd per foot in Kane County to 5000 gpd per foot in Kankakee County.

The southward decrease in transmissivity of the Cambrian-Ordovician aquifer reflects, among other things, a decrease in transmissivity of the Ironton-Galesville Sandstone. This decrease is not related to the thickness of the Ironton-Galesville because thickness increases southward (fig. 7). Rather, it is related to the carbonate content, which increases southward (fig. 10). This decreases the permeability and the transmissivity of the sandstone.

Specific capacity data also give some approximation of aquifer properties of the Ironton-Galesville Sandstone, though the specific capacity of a well is influenced by well construction as well as by the permeability of the aquifer. Few wells are uncased only in the Ironton-Galesville Sandstone. In northeastern Illinois, where limited data are available, the specific capacities of wells open only in the Ironton-Galesville range from 1.7 to 7.0 gpm per foot and average 3.6 gpm per foot (Walton and Csallany, 1962, p. 19, 20). These specific capacities decrease southward from approximately 4.0 gpm per foot in Kane County to 3.0 gpm per

foot in Kankakee County and agree with the coefficient of transmissibility, which also decreases in a southward direction.

Permeability and porosity measurements of cores at several gas storage sites in northeastern Illinois (fig. 20) afford a basis for comparing the Galesville and Ironton sections of the aquifer, for comparing core values with values derived from pumping tests, for observing regional trends, and for comparing the Ironton-Galesville with other sandstone aquifers of northern Illinois.

Extensive testing of the Ironton and Galesville Sandstones was undertaken by the Natural Gas Storage Co. of Illinois at Herscher, Kankakee County. In one typical well the sandstones were penetrated between depths of 1643 and 1878 feet. The section to 1770 feet was referred to the Ironton Formation and consists of coarse, glauconitic, dolomitic sandstone, interbedded with hard, silty dolomite streaked with dark shale. The section from 1770 to 1878 feet was referred to the Galesville Formation and consists of very fine to coarse, slightly glauconitic sandstone and fine to coarse, white, incoherent sandstone.

Horizontal and vertical permeability and porosity were determined from core samples at intervals of one or two feet. Permeabilities were measured in millidarcies. A darcy (1000 millidarcies) is a specific permeability unit of a porous medium, independent of fluid properties, and is related to the field coefficient of permeability (P) under conditions in northern Illinois approximately as follows: 1 darcy=18.2 P. Permeabilities greater than 500 to 1000 millidarcies (10 to 20 gpd/ft²) characterize good aquifers.

Wide variation in permeability and porosity occurs in the Ironton section between adjacent sandstone and dolomite beds. Horizontal permeabilities range from less than 1 to 2500 millidarcies. Vertical permeabilities range from less than 1 to 645 millidarcies. Porosities range from less than 1 to over 33 percent.

Some variation also occurs in the Galesville section. Most of the section is composed of thick, highly permeable beds with low permeabilities restricted to thin zones. For example, the section from 1775 feet to 1845 feet has horizontal permeabilities that are greater than 20 millidarcies, many of them greater than 100 millidarcies, whereas the section from 1845 to 1860 feet has permeabilities less than 10 millidarcies. Horizontal permeability for the entire Galesville section ranges

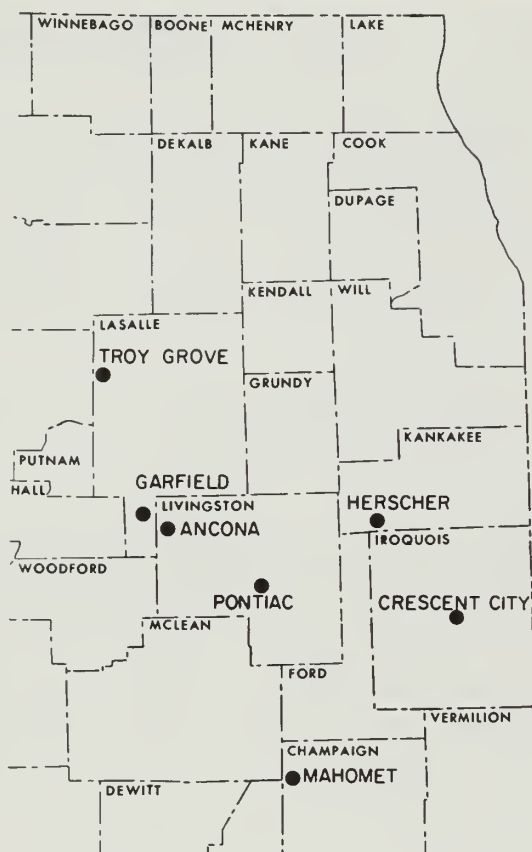


Figure 20 - Gas storage projects in northeastern Illinois.

TABLE 4 - FREQUENCY OF CORE SAMPLES WITH INDICATED
HORIZONTAL PERMEABILITY RANGES

Permeability (millidarcies)	Percent of samples	
	Ironton (88*)	Galesville (81*)
Less than 1	56	14
1 to 10	11	15
10 to 100	15	22
100 to 1000	15	30
Greater than 1000	3	18

*Total samples tested

from less than 1 to almost 8000 millidarcies. Vertical permeability ranges from less than 1 to 1259 millidarcies. Porosity ranges from 11 to 35 percent.

The difference in permeability between the Ironton and Galesville is shown by the distribution of measured horizontal permeabilities in core samples (table 4).

More than half of the core samples from the Ironton have permeabilities of less than one millidarcy, whereas only 14 percent of the samples of the Galesville have permeabilities of less than 1. Almost half of the core samples from the Galesville have permeabilities of more than 100 millidarcies.

Straight mathematical averages of horizontal permeabilities of the Galesville section in three wells at Herscher are 558, 449, and 643 millidarcies, whereas the porosities from the same wells average 21.1, 17.2, and 19.3 percent. Vertical permeabilities of cores are consistently less than horizontal permeabilities, commonly about 40 percent of the latter.

Straight mathematical averages probably represent minimal values because the most permeable and porous material in the section is poorly consolidated and was not fully recovered in the coring. Weighted averages were therefore used in evaluating the Galesville Sandstone, to take into account core loss and the probable conditions between core plugs. On this basis, the effective porosity of the Galesville was estimated as 25 percent, the horizontal permeability as 1600 millidarcies, and the vertical permeability as at least 600 millidarcies (Bays, 1952).

When the estimated horizontal permeability of 1600 millidarcies is converted to field permeability units and multiplied by aquifer thickness (120 feet of permeable beds estimated by inspection of permeability data from well discussed above), the coefficient of transmissibility (T) is 3500 gpd per foot. Walton and Csallany (1962) estimated T to be 5000 gpd per foot in Kankakee County.

Permeability measurements on cores from other gas storage sites give erratic permeability profiles in the dolomites and sandstones of the Ironton, and higher, more consistent permeabilities in the Galesville Sandstone. A general southerly or southeasterly decline in average permeability of Galesville Sandstone cores is indicated, but fairly wide variations in average permeabilities are frequently present between wells in the same gas storage structure. Three wells on the Herscher structure have average horizontal permeabilities within the Galesville of 558, 449, and 643 millidarcies. At Crescent City, two wells have permeabilities within the Galesville of 518 millidarcies (33 feet of core) and 81 millidarcies (28 feet of core).

At Garfield, 77 feet of Galesville core gave an average permeability of 907 millidarcies and an average porosity of 21.7 percent. At Ancona, a few miles south, 37 feet of Galesville gave an average permeability of 638 millidarcies and an average porosity of 22.5 percent. At Pontiac, 39 feet of Galesville gave an average permeability of 458 millidarcies and an average porosity of 20.2 percent. At Mahomet, 56 feet of the more permeable, basal Galesville Sandstone gave an average permeability of 777 millidarcies and an average porosity of 17.8 percent.

The core testing from gas storage projects shows that the Galesville Sandstone is generally more permeable and porous than the St. Peter Sandstone, and substantially more permeable and porous than the upper part of the Mt. Simon Sandstone. However, permeabilities and porosities of the Galesville relative to the other sandstones vary regionally.

The Ironton-Galesville Sandstone, being overlain by a series of less permeable rocks of Cambrian and Ordovician age, contains water under artesian pressure. Pumpage through the years has modified pressure conditions, producing local depressions of the original pressure surface of the multiple aquifer system, but at no place in Illinois has dewatering of the Ironton-Galesville occurred. In fact, the artesian pressure surface of the Ironton-Galesville Sandstone probably stands several hundred feet above the top of the formation. Data are not available to define pressures or paths of water movement within the Ironton-Galesville other than in general terms.

The piezometric surface and the water quality and temperature variations of the Cambrian-Ordovician aquifer system suggest that recharge occurs in an area of DeKalb, Boone, McHenry, and Winnebago Counties, Illinois (Suter et al., 1959, p. 59-60; Walton and Csallany, 1962, p. 10). In this area, where the relatively impermeable shale of the Maquoketa Group is not present, there is sufficient hydrologic connection between the upper and deeper bedrock to permit water to percolate downward into the Ironton-Galesville. The flow of the recharge area is at accelerating rates eastward toward pumping centers along the Fox River, and also at Chicago and Joliet.

Water recharged to the Ironton-Galesville Sandstone moves down-dip to considerable depth in northern Illinois before becoming mineralized to a level that limits further human use. The wide transmission of usable water is probably a function mainly of the high permeability of the aquifer. Regional variation in the depth to which usable water occurs in the sandstone is a result of differences in distance from recharge area, permeability, structure, flow system, and probably other factors. Usable water is obtained from the Ironton-Galesville as deep as 1700 feet below sea level in western Illinois, at Abingdon, Knox County, 2000 feet below sea level along the LaSalle Anticlinal Belt, at Oglesby, LaSalle County, and 900 feet below sea level in northeastern Illinois, at Wilmington, Will County. South of these locations, water in the Ironton-Galesville is probably too highly mineralized for most uses.

SUMMARY AND CONCLUSIONS

During late Cambrian time, the Upper Mississippi Valley was a broad, shallow, cratonic shelf. The Ironton and Galesville Sandstones were spread southward across this shelf to central Illinois, where they rapidly graded into sandy dolomite (fig. 21). The southerly direction of transport is shown by increases in thickness and dolomite content and by decrease in the maximum diameters of the sand grains in that direction.

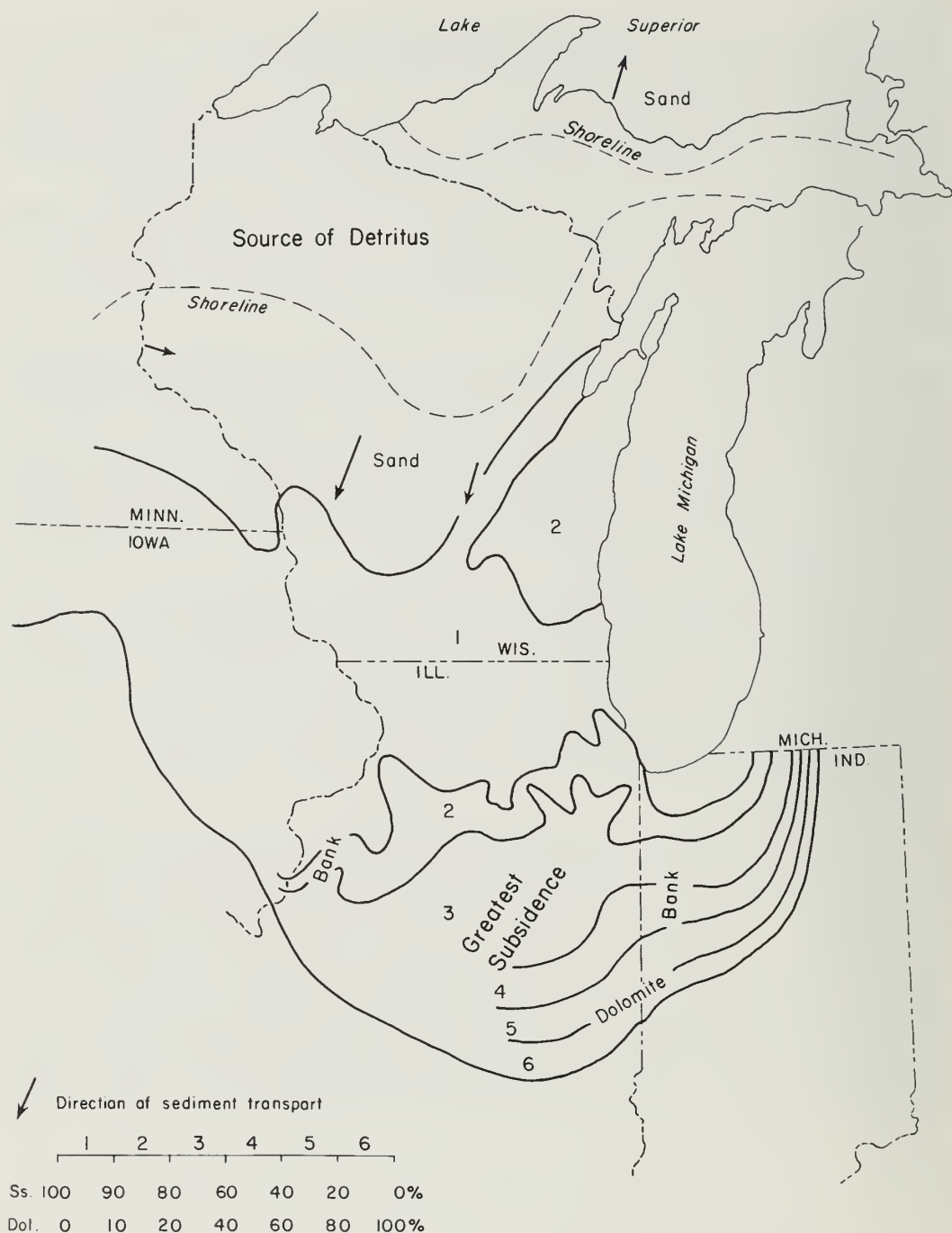


Figure 21 - Paleogeography and depositional environments during Ironton and Galesville time.

Except where dolomitic and locally silty, the Ironton and Galesville Sandstones are well sorted orthoquartzites composed almost entirely of moderately well rounded quartz grains with minor amounts of silt, clay, and feldspar. The heavy minerals are principally well rounded tourmaline and zircon with varying amounts of garnet, ilmenite, and leucoxene, and scattered grains of hornblende and epidote.

Cross-bedding data indicate currents to the south and southwest and locally to the east in western Wisconsin. The mean orientation of cross-bedding for both sandstones is 226 degrees with a variance of 12,819 and a standard deviation of 113 degrees. The large variation of direction of cross-bedding over most of the area of outcrop and the values of variance and standard deviation are not comparable with those of previously reported marine shelf or nonmarine fluvial deposits. Rather, it is typical of an extremely broad, shallow, marine shelf with a slope measured in seconds of a degree.

The Ironton and Galesville Sandstones were derived from preexisting sediments covering the Northern Michigan Highlands and secondary sources to the west and northeast. Near the end of Eau Claire time, deposition consisted primarily of fine-grained sandstones and siltstones in Wisconsin grading southward into shales, siltstones, and silty dolomites in Illinois. Eau Claire deposition was terminated by retreat of the seas and local erosion in central Wisconsin along the Wisconsin Arch. In Illinois, deposition was continuous from Eau Claire time to Galesville time, but the character of the sediments changed from fine to coarser clastics. The seas readvanced during Galesville deposition but did not reach as far north as the Eau Claire seas. Slow subsidence of the shelf allowed reworking of the sands that were swept down into Illinois from the source areas to the north. Southward, near the depositional edge, carbonate deposition was dominant in clear, shallow seas. Shallow banklike conditions prevailed in eastern and western Illinois.

A slight increase in subsidence resulted in the further transgression of the seas northward during deposition of the Ironton Sandstone. This northward transgression was accompanied by an increase in carbonate deposition and less reworking of the sands by the currents. By the close of Ironton deposition, the seas had covered the Northern Michigan Highlands and the principal source area was then located to the northeast in Canada. A minor regression of the seas ended Ironton deposition.

Stable conditions of sand deposition made the Ironton and Galesville Sandstones the most consistently permeable aquifer in northern Illinois and southern Wisconsin. The transmissivity of the aquifer decreases from north to south, as carbonate content increases. The Galesville Sandstone is more permeable than the Ironton.

Although the Ironton-Galesville aquifer has been a source of ground water for more than 100 years, large supplies of potable water under high artesian head are still available from the aquifer in the northern quarter of Illinois.

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Illinois State Geological Survey Circular 403
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CIRCULAR 403

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